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DESIGN OF A SOLID WASTE MANAGEMENT SYSTEM FOR THE EASTERN APPALACHIA HEALTH REGION OF NORTH CAROLINA

John M. Sweeten

Environmental Protection Agency
Rockville, Maryland

1972

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This solid waste management
Open-File Report (SW-80.of) was written
by JOHN M. SWEETEN

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1972

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SUMMARY AND RECOMMENDATIONS

Summary

The solid waste management conditions in Alexander, Burke, Caldwell, and McDowell Counties, North Carolina, were analyzed for the purpose of developing practicable solutions to the problem of improper solid waste disposal in the region. This study was conducted by personnel of the Office of Solid Waste Management Programs, Environmental Protection Agency, at the request of the Regional Health Council of Eastern Appalachia, Morganton, North Carolina.

The 1679 square mile study region embraces a population of 167,000 persons who generate an estimated 154,000 tons of solid waste annually. In 1968, public and private solid waste collection agencies collected over 124,000 tons/year of refuse produced by municipal sources (industrial, commercial, and institutional establishments and residences) representing a population of about 97,000 residents. The remaining 38 percent of the population, comprised mostly of rural families, produced an estimated 22,500 tons/year of refuse that was not collected. Many thousands of recreational users of publicly-and privately - owned parklands in the four-county region contribute approximately 800 tons/year of solid waste.

The four-county region of Eastern Appalachia contains 24 general use land disposal sites, 23 of which are open burning dumps. In addition, at least 325 promiscuous dump sites are located along roads and highways in the region. This epidemic of open dumping of solid waste threatens water and air quality, public health, and scenic beauty of the region.

The two major factors contributing to the improper disposal of solid waste apparently are (a) fragmented authority over solid waste collection and disposal and (b) the lack of solid waste collection service

to rural residents and recreational visitors. Any logical attempt to effectuate an adequate solid waste disposal system for the Eastern Appalachia region must eliminate these two deterrents.

Several alternative regionalization schemes and land disposal systems were considered and subjected to economic analysis. The purpose of this analysis was to determine the optimum number and location of regional sanitary landfills which would minimize the combined regional cost of sanitary landfill operation and solid waste transportation. Equipment, personnel, and monetary requirements for a bulk container solid waste collection system serving rural residents and recreational areas currently without collection service were also determined.

Based on the economic analysis along with political and other considerations, a regional solid waste management system consisting of four sanitary landfills and a rural bulk container solid waste collection system was recommended for implementation. Total capital cost for equipment and land recommended for the project would be $678,060. The annual operating costs (including depreciation) of the complete system would be $264,849/year which amounts to $1.62/ton of solid waste or $1.49/person/year.

Recommendations

The county commissioners of Burke, Caldwell, McDowell, and Alexander Counties, North Carolina, should form a regional solid waste management commission. This commission, properly constituted by law, should regulate solid waste management practices in the region under uniform regional solid waste ordinances and regulations.

The regional solid waste management commission should establish four sanitary landfills, one each in McDowell, Burke, Caldwell, and Alexander Counties. Simultaneously, it should close all open dumps in the four-county region using recommended procedures. Standard design and operating procedures for the four sanitary landfills should be adopted. These four sanitary landfills should be located as near as possible to the population centers of each county (i.e., Marion, Morganton, Lenoir, and Taylorsville) in order to minimize the cost to the region for transporting solid waste. Actual selection of the sanitary landfill sites should be performed by the regional solid waste management commission working in conjunction with State sanitary engineers and local health officials. The recommended land, equipment and personnel requirements along with the estimated cost to the project for installing and operating the sanitary landfills are given in Tables 2, 3, 9, 10, 11, 12, and 13.

Finally, the regional commission should effectuate a rural bulk-container solid waste collection system to provide collection service to those permanent residents and recreational visitors to the region who are not presently served by either public or private collection. Requirements for equipment and personnel to fully implement the proposed collection system are listed in Appendix G. Unless an adequately-sized

rural collection system is implemented, regulations prohibiting solid waste burning and the dumping of solid waste in unauthorized areas will not be obeyed and cannot be effectively enforced since solid waste transportation costs without such a system will be prohibitive. The recommended solid waste management system could be installed in several phases as funds are available. Initial and operating costs of the system can be derived from uniform taxation of all residents and business establishments within the four-county region. Other sources of revenue could include the Appalachia Regional Commission's grant programs, loans, and the sale of revenue bonds.

INTRODUCTION

At the time of this study, the prevailing solid waste management practices in the Eastern Appalachia Health Region of North Carolina comprised of Alexander, Burke, Caldwell, and McDowell counties, were unacceptable. The 167,177 residents and many thousands of recreational visitors (1.8 million visitor- and camper-days/yr) disposed of their solid wastes in 23 dumps, in approximately 325 illegal roadside dumps, and in lakes, streams, and forests. Only one land disposal site in the entire region could be classified as acceptable according to State standards. The existing solid waste disposal practices threatened the region's air and water quality, scenic beauty, and public health. Probably the major factor causing the proliferation of open dumps has been the unavailability of refuse collection service to many residents.

Within the next few years, the existing dumps in the Eastern Appalachia Health Region will be closed by action of the North Carolina State Health Department. At that time, the municipalities and counties involved will be forced to provide acceptable solid waste disposal systems. To prevent the haphazard and uneconomical development of sanitary landfills in the future, a regional solid waste management system encompassing all residents of McDowell, Caldwell, Burke, and Alexander Counties was needed.

In June 1970, the Regional Health Council of Eastern Appalachia requested technical assistance from the Bureau of Solid Waste Management (BSWM), U. S. Public Health Service, in devising a practicable solid waste management system. Accordingly, a study team from BSWM collected and analyzed pertinent data, formulated and evaluated solid waste

management system alternatives, and recommended a regional solid waste collection and disposal system to serve the four-county Eastern Appalachia Region.

A final report of the study was submitted to the Regional Health Council of Eastern Appalachia in September, 1970. Data collected during the study are presented herein, with special attention given to the data analysis procedures utilized. Conclusions made are based on these data and their analysis. It is hoped that this report will provide a basis for future design of similar solid waste management systems.

THE EASTERN APPALACHIA HEALTH REGION

General Description

The Eastern Appalachia Health Region of North Carolina, is comprised of four contiguous counties located in west central North Carolina as shown in Figure 1. The total land area of 1679 sq mi is divided among the four counties as follows: Alexander - 255 sq mi, Burke - 506 sq mi, Caldwell - 476 sq mi, and McDowell - 441 sq mi.[1]

Physical features of these counties typify two of North Carolina's major phsiographic provinces, the Blue Ridge Mountains and the Inner Piedmont Plateau. The Blue Ridge Mountains form the northern and western boundaries of the region. Along the Blue Ridge front, altitutes range from 1300 ft near Lake James to 6684 ft on the summit of Mt. Mitchell, which lies four miles west of the McDowell County line in Yancey County. The greatest topographic relief occurs along the eastern slope of the Blue Ridge province, where high gradient streams flow into the Catawba and Yadkin Rivers. The base of the mountains, where the altitude is approximately 1300 to 1500 ft, marks the boundary between the two physiographic provinces. The topography of the Inner Piedmont, having a gentle to moderate relief, contrasts sharply with the steep gradients and ridges of the Blue Ridge Mountains.

Descriptions of the climate, topography, principal drainage features, basic economy and water supply source for each of the four counties considered have been compiled in other studies.[2,3,4]

Population Magnitude and Distribution

Population data for the region was compiled for the years 1940, 1950, 1960, and 1970 from Bureau of Census, U. S. Department of Commerce records.[5,6]

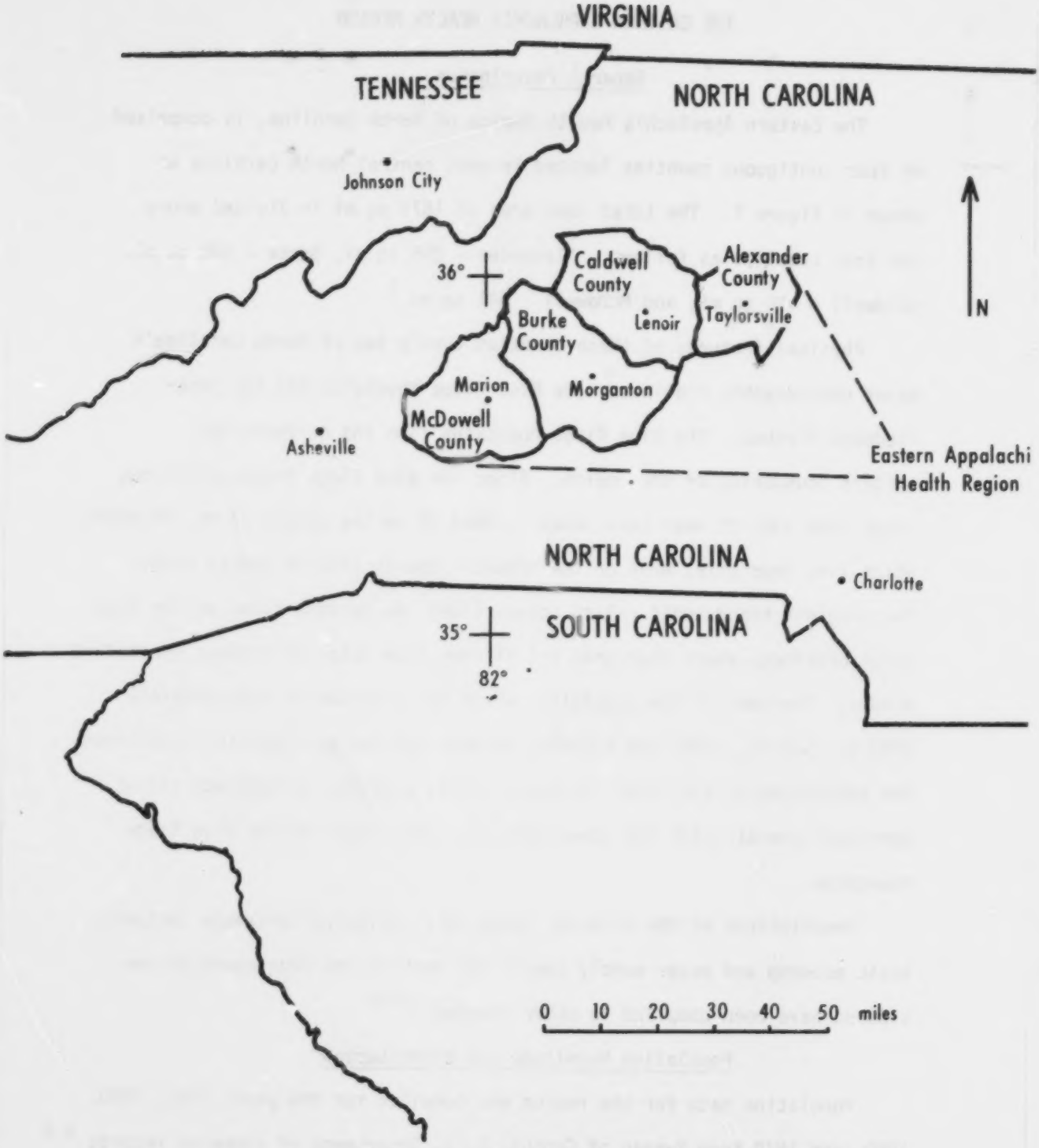


Figure 1. Geographic location of Eastern Appalachia Health Region, North Carolina

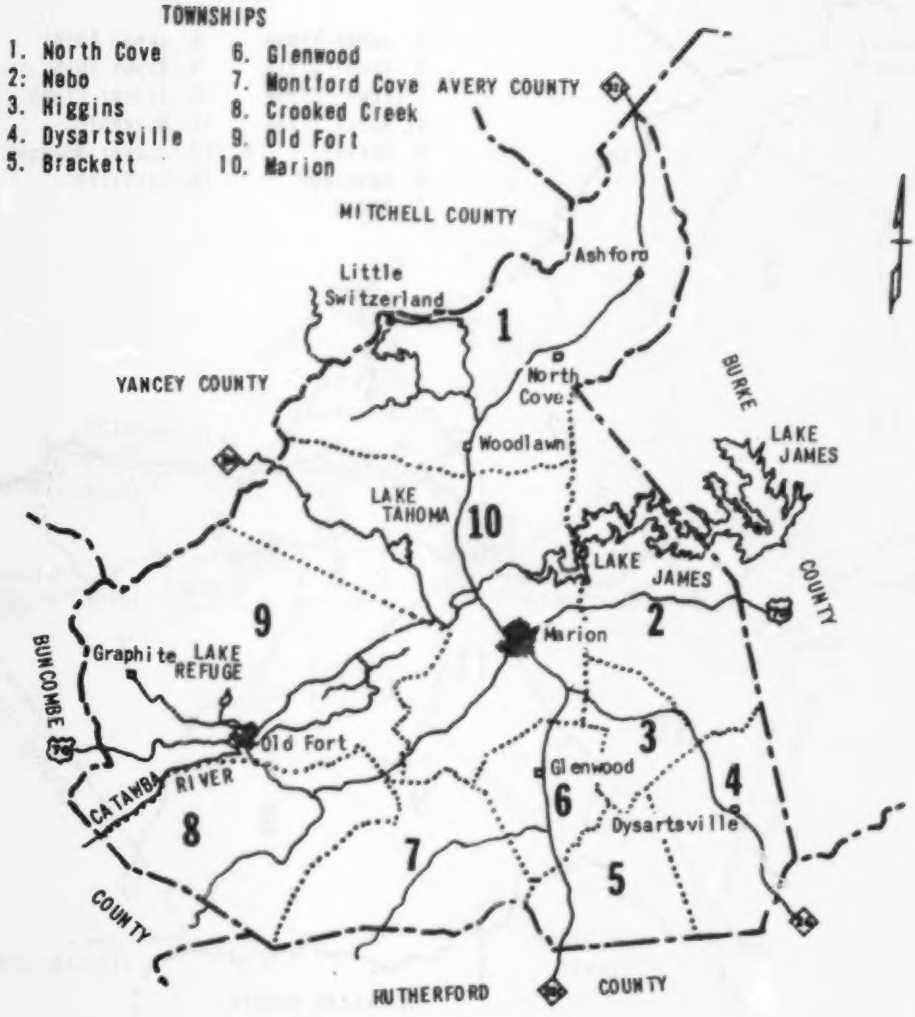
Population projections for 1980 and 1990 were then computed by the incremental increase method and are presented in Table 1.

The 1940, 1950, 1960, and 1970 populations of each township and principal municipality within the four-county region are presented in Appendices A and B. The locations of the townships and municipalities are shown on county maps in Figures 2 - 5.

TABLE 1

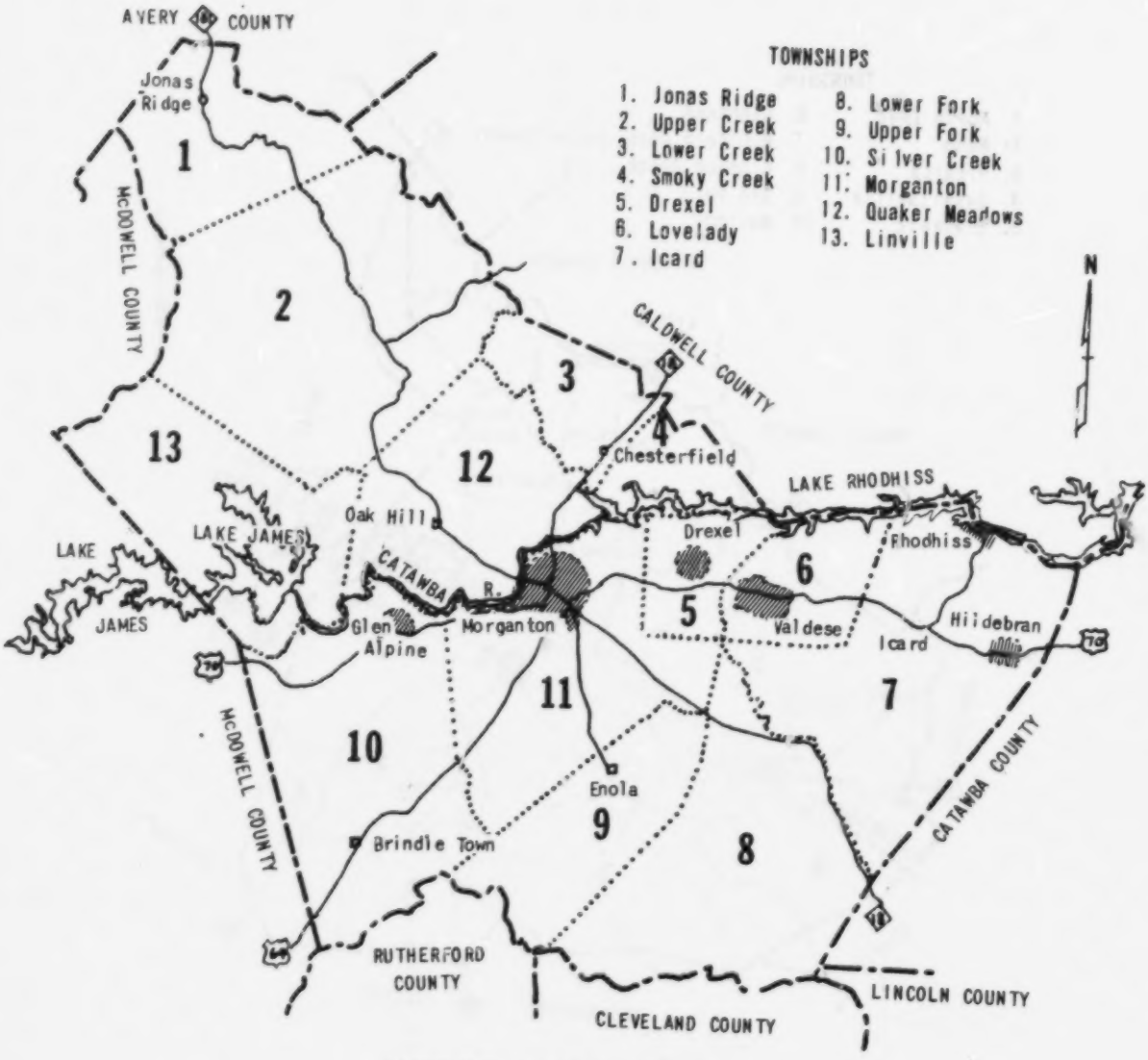
POPULATION OF COUNTIES IN EASTERN APPALACHIA REGION

County	Population in Census Years				Projected Populations	
	1940	1950	1960	1970	1980 Est.	1990 Est.
Alexander Co.	13,454	14,554	15,625	19,466	22,841	27,587
Burke Co.	38,615	45,518	52,701	60,364	67,994	76,004
Caldwell Co.	35,795	43,352	49,552	56,699	63,462	70,020
McDowell Co.	22,996	25,720	26,742	30,648	33,790	37,523
Total	110,869	129,144	144,620	167,177	188,087	211,134



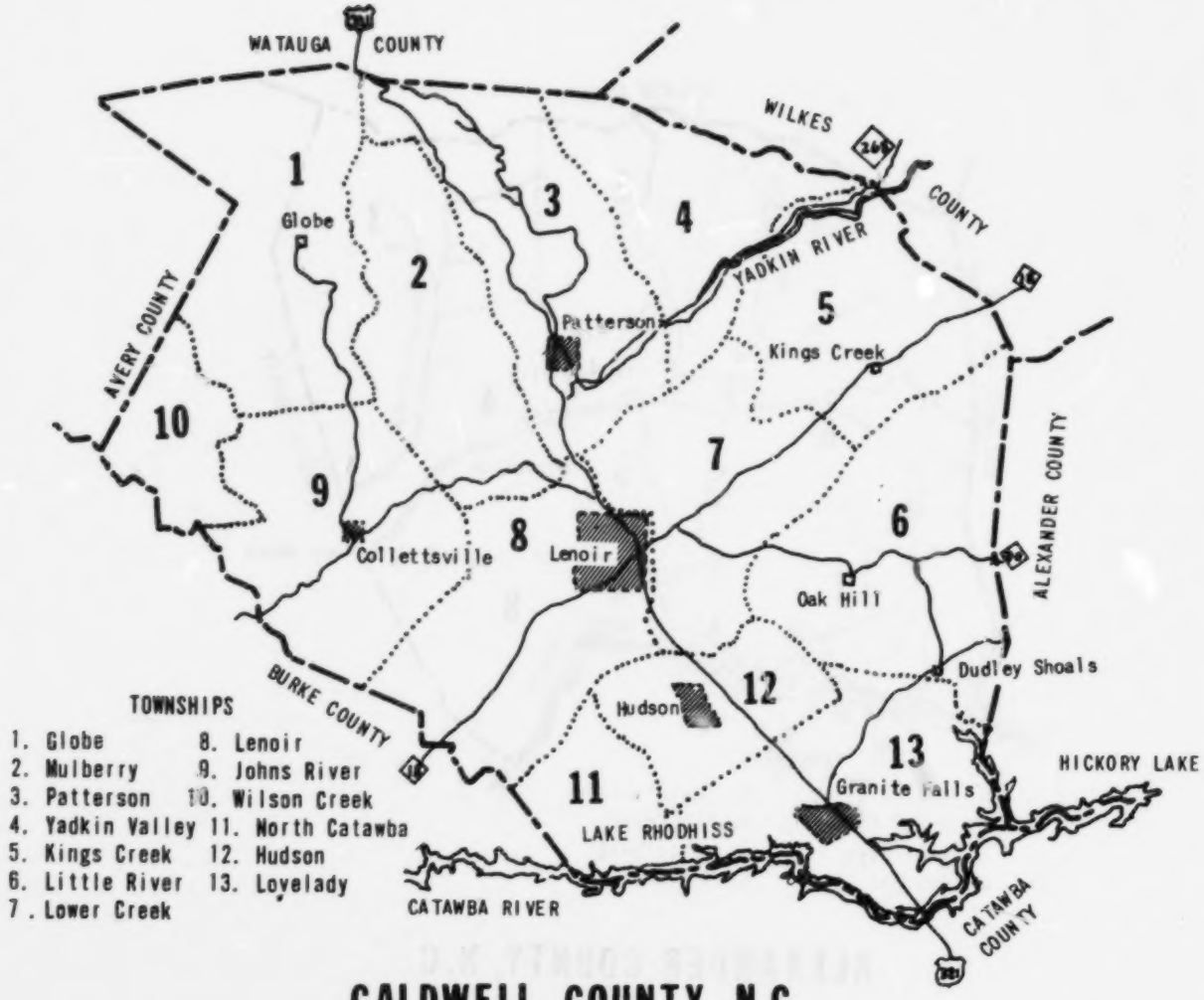
McDOWELL COUNTY, N.C.

Figure 2. Map of McDowell County



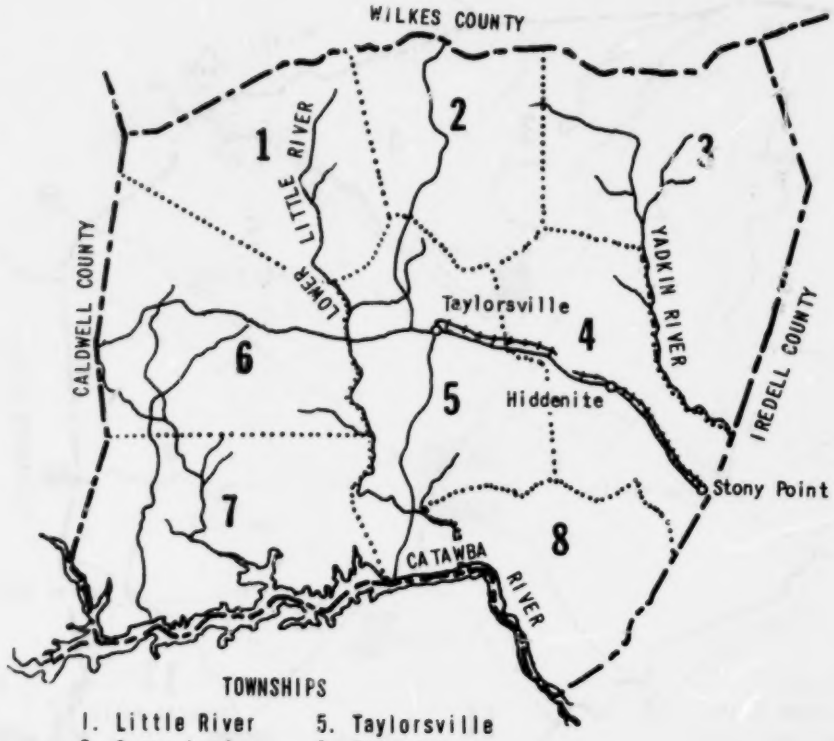
BURKE COUNTY, N.C.

Figure 3. Map of Burke County



CALDWELL COUNTY, N.C.

Figure 4. Map of Caldwell County



ALEXANDER COUNTY, N.C.

Figure 5. Map of Alexander County

EXISTING SOLID WASTE MANAGEMENT PRACTICES

Present Disposal Sites

The four-county region under investigation contains 23 open burning dumps and one sanitary landfill. The quantity of solid waste received at each site and the type of site ownership are listed in Table C-1, while Figure C-1 depicts the locations of each land disposal site.

In addition to the general-use land disposal sites,a 1969 survey performed by county sanitarians revealed that at least 325 promiscuous dumps are located along roads and highways in the region. The annual quantity of solid waste deposited at these dump sites was not readily determinable.

Present Solid Waste Collection Systems

Those municipalities operating public solid waste collection systems within the region are identified in Appendix D. Detailed information concerning the crew sizes, type of collection service performed, collection frequencies, and collection costs could not be determined in the brief study period available. The capacities of the vehicles listed in Table D-1 are known to range from 14-18 cu yd each (except for a single 25 cu yd compactor truck), so that an average capacity of 16 cu yd per vehicle was assumed in the transportation cost analysis which follows.

Detailed information concerning private solid waste collection agencies in the region could not be obtained. From the State survey, however, it is known that approximately 60,000 residents and most industries are served by private collection. Accordingly, approximately 63,000 residents, living mostly in rural areas, do not receive any form of collection service.

Solid Waste Collection Rates

Results obtained from the 1968 State survey of solid waste management practices revealed that 124,000 tons/year of solid waste was collected by municipal and private collection agencies serving McDowell, Burke, Caldwell, and Alexander counties. This quantity of solid waste, produced mainly by municipal sources (such as residences, industrial establishments, institutions, and commercial enterprises), represented a population of 97,700 persons and a solid waste collection rate of 6.96 lbs/capita/day (or 1.27 tons/capita/year). In 1968, approximately 38 percent of the region's population did not receive organized collection service but generated an estimated 22,500 tons/year of solid waste, primarily from rural families. Therefore, in 1968, the average solid waste generation rate for rural residents was 2.0 lbs/capita/day (or 0.37 tons/capita/year). The composite solid waste generation rate was 5.05 lbs/capita/day (or 0.92 tons/capita/year).

Recreational Solid Waste Generation

The amount of solid waste generated by visitors and campers within public recreational areas in the Eastern Appalachia region was estimated. These recreational areas include the Pisgah National Forest and three lakes along the Catawba River.

The Pisgah National Forest and its associated wildlife refuges occupy 66,358 acres in McDowell County; 13,160 acres in Burke County; and 49,411 acres in Caldwell County. In these counties, solid waste from the national forest and adjacent wildlife refuges is collected by Forest Service personnel and is disposed of in four land disposal sites on Government property. An exception occurs during annual clean-up projects when private contractors

haul the excess solid waste to public or private land disposal sites.

According to Forest Service records, in 1969 the Pisgah National Forest received the following degree of usage: 65,300 visitor-days in McDowell County; 106,200 visitor-days in Burke County; and 112,600 visitor-days in Caldwell County. By assuming that one-third of these visits were overnight stays while the remaining two-thirds were merely day-use visits, the recreational solid waste quantities were estimated by applying waste collection rates of 0.96 lbs/visitor-day and 1.26 lbs/camper-day for day-use and overnight visits, respectively.[7] Of the resulting solid waste collection rate of 151 tons/year, the quantity of solid waste entering land disposal sites in neighboring counties can be expected to be negligible as compared to quantities generated by the area's residents; therefore, was not considered in the design.

Three major lakes, used as power pools for hydroelectric energy generation, lie within or border the Eastern Appalachia region. These reservoirs along the Catawba River are Lake James, Lake Rhodhiss, and Lake Hickory. The Duke Power Company of Charlotte, North Carolina owns the lakes and 7,375 acres of adjacent shoreline property and it invites public use of these recreational areas. Unfortunately, this use is often accompanied by indiscriminant littering and dumping of solid waste. Moreover, Duke Power Company estimated that 500 to 1000 permanent residents living near the recreational areas persistently dump household solid waste on the power company's property. Legal action has not been initiated against these violators, however, because of possible adverse public relations.

The annual number of day-use and overnight-visits to Lakes James, Rhodhiss, and Hickory were estimated by Duke Power Company in 1968 and are presented in Appendix E, Table E-1. The following numbers of private

cottages are situated on shoreline property: Lake Rhodhiss--15 cottages, Lake Hickory--500 cottages, Lake James--62 cottages.

The quantity of solid waste generated at each recreational area was computed using solid waste generation rates of 0.96 pounds/visitor-day for day-use visits, 1.26 pounds/camper-day for overnight visits, and 2.13 pounds/occupant-day for private cottages for which 40 occupant-days/year was assumed.[7] The resulting solid waste quantities are listed in Table E-2 according to recreational areas and in Table E-3 according to townships and counties bordering the lakes.

The total recreational solid waste quantity of 663 tons/year being generated on Duke Power Company property within the study area is equivalent to that produced by 1,811 permanent rural residents. From the standpoint of solid waste disposal operations at regional sanitary landfills, this waste quantity is negligible for practical purposes. However, it does represent a significant amount when considering the capacity requirements of the proposed rural bulk container solid waste collection system, as will be shown later.

Summary of Existing Conditions

The solid waste disposal practices prevailing in Burke, Caldwell, Alexander, and McDowell Counties are clearly unacceptable. However, the factors contributing to the proliferation of open dumps in the region could be virtually eliminated by centralizing authority over solid waste management, establishing regional sanitary landfills, and extending solid waste collection service to rural and recreational areas.

ANALYSIS OF SOLID WASTE MANAGEMENT SYSTEM ALTERNATIVES

Several alternative regionalization schemes, disposal system configurations, and transportation modes were considered and subjected to

economic analysis. The purpose of this analysis was to determine the number and location of sanitary landfills which would minimize the combined cost of operating a regional sanitary landfill system and transporting solid waste from source to disposal site. Based on the economic analysis along with political and other considerations, a regional solid waste management plan was finally selected for implementation.

Volume reduction by incineration was not considered a viable system alternative because of the small population magnitude and solid waste quantity, dispersion of population centers, and relative abundance of land suitable for sanitary landfilling.

In performing the economic analysis, the number of sanitary landfills assumed for the four-county region was varied through the following levels: one, three, four, and five landfills. For each landfill configuration analysis, the townships (the smallest available census tracts) were grouped into collection and disposal zones or subregions, each of which would contain a sanitary landfill. These subregions were formed on the basis of township population, population distribution, and accessibility via all-weather roads. Based on the subregion populations and the solid waste generation rates reported earlier, the size, personnel and equipment requirements, and operating cost of a sanitary landfill in each subregion were determined. The total cost, T_s, to the regional project of administering and operating the sanitary landfill system was then ascertained by summing the costs for the subregional landfills.

Within each subregion, the optimum location for a land disposal site was determined by the trial-and-error process of minimizing the number of person-miles (i.e. the product of population and travel distance) between township population centroids and assumed landfill locations. After the optimum sanitary landfill locations had been pinpointed in this

manner, the cost of transporting solid waste from each township to the disposal site was computed for varios methods of transportation, including a rural bulk collection system. The transportation costs for townships were summed to yield the total transportation costs, T_t, for the entire region.

Finally, the total regional cost of each alternative, T_c, was computed as follows:

$$T_c = T_s + T_t \qquad (1)$$

The alternative yielding the least value of T_c was the most economical solution.

Analysis of Sanitary Landfill Operating Costs

The total cost, T_s, to the four-county Eastern Appalachia region of operating a system of sanitary landfills was computed in the following manner:

$$T_s = C_{fp} + N\,C_{fs} + \sum_{i=1}^{N} C_{vi} \qquad (2)$$

in which: C_{fp} = sum of annual project fixed costs that are not related to the number of sanitary landfills, \$/year.

C_{fs} = sum of annual fixed costs at each sanitary landfill that are independent of landfill size and number, \$/year/landfill.

C_{vi} = sum of annual size-related costs (land and equipment costs) at each sanitary landfills, \$/year.

N = number of sanitary landfills in the region

i = 1, 2, ..., N

The three cost components on the right hand side of equation (2) are examined in the following analyses.

Project Fixed Costs. Fixed costs to the regional project that are independent of the number and size of sanitary landfills include salaries

of the project director and office staff, office supplies, engineering consultant services, and travel of the project director. These costs were specified by the Regional Health Council of Eastern Appalachia based on their knowledge of local labor conditions and project needs. The cost of closing and rehabilitating the 24 existing land disposal sites was also included. A summary of the project fixed costs is presented in Table 2, from which C_{fp} = $20,990/year.

The fixed cost at <u>each</u> sanitary landfill site includes personnel-related costs, utilities, access roads, fences, signs, and mechanical supplies. Each of these costs, listed in Table 3, was assumed to be unrelated to the number of size of sanitary landfills selected. To the extent that this assumption was violated in actuality, such as for site fencing, it is hoped that a sufficient allowance was made. The sum of the costs in Table 3 (C_{fs} = $14,973/year) should be multiplied by the number of sites to be installed in the four-county region to yield the total annual costs for non-size related expenditures.

All capital costs were depreciated by the straight line method using a maximum life of 10 years since the sanitary landfills were sized for a 10-year capacity. Longer periods of depreciation would be justified if the sanitary landfill sites actually purchased have sufficient capacities.

TABLE 2

ANNUAL PROJECT FIXED COSTS THAT ARE INDEPENDENT OF NUMBER OF SANITARY LANDFILLS

Cost Item	Number or Quantity	Unit Price	Initial Cost $	Estimated Life Years	Annual Cost $/Year
1. Program Director	1	$12,000/yr	---	---	$12,000
2. Fringe Benefits of Director @ 15%	1	1,800/yr	---	---	1,800
3. Administrative Services (Secretarial)	1	2,000/yr	---	---	2,000
4. Office Supplies	---	---	---	---	500
5. Audiovisual Equipment	---	---	300	10	30
6. Travel of Program Director	---	---	---	---	1,800
7. Pick-up Truck	1	2,800	2,800	5	560
8. Consultant Services	---	---	5,000	10	500
9. Closing or Rehabilitation of Existing Dumps	24	750	18,000	10	1,800
10. TOTAL			$26,100		$20,990/yr

TABLE 3

NON-SIZE-RELATED COSTS*
AT EACH SANITARY LANDFILL

Item of Cost	Number or Quantity	Unit Price	Initial Cost $	Estimated Life Years	Annual Cost $/Year
1. Salary of Landfill Operator	1	$6,000	---	---	$6,000
2. Salary of Asst. Operator	1	4,800	---	---	4,800
3. Fringe Benefits of Landfill Employees at 15%	2	1,620	---	---	1,620
4. Sanitary Facilities	---	---	$1,250	10	125
5. Utilities & Telephone	---	---	---	---	500
6. Office Shelter or Trailer	1	4,000	4,000	10	400
7. Fencing and Signs	---	---	2,250	10	225
8. Personnel Training, including travel	2	300	600	4	150
8. Uniform Rental	2	120	---	---	240
10. Tools and Mechanical Supplies	---	---	500	4	125
11. Access Roads	1/4 mi	35,000/mi	7,875	10	788
12. Total			$16,745		$14,973

* Personnel and ancillary facility costs were specified by the Regional Health Council of Eastern Appalachia based on their knowledge of local labor conditions and project needs.

Size-Related Costs of Sanitary Landfills. Costs of owning and operating a sanitary landfill that are directly related to the quantity of solid waste received (i.e. landfill size) include initial site costs, site preparation costs, and equipment owning and operating expenses. These size-related costs were determined for a solid waste disposal system in Eastern Appalachia involving one, three, four, and five sanitary landfills (i.e. N = 1, 3, 4, 5).

One-Landfill Alternative. The procedure for determining size-related sanitary landfill operating costs, C_{vi} is herein illustrated for the one-landfill alternative. This procedure was also followed for alternatives involving a greater number of sanitary landfills.

Regardless of its location, a single sanitary landfill for Eastern Appalachia would have to handle the total waste tonnage from the design population (average of 1970 and 1980 populations) of 177,632 residents producing a total of 163,400 tons/year of solid waste. Assuming a compacted solid waste density of 850 lbs/cu yd (0.425 tons/cu yd) in the completed landfill and a compacted cover material to refuse ratio of 1:4 (volume basis), the design rate of utilization of landfill volume, V_f, can be computed as follows:

$$V_f = \left(\frac{\text{Annual weight of solid waste}}{\text{Compacted solid waste density}}\right) \times \frac{\text{Volume of refuse and cover material}}{\text{Volume of refuse}} \qquad (3)$$

$$= \frac{(163{,}400 \text{ tons/year})\ (1.25)}{(0.425 \text{ tons/cu yd})}$$

V_f = 480,000 cubic yards/year, or 297 acre-ft/year

The landfill surface area to be actually utilized, A_f, can be computed from the following relationship:

$$A_f = V_f\ Y/D \qquad (4)$$

where Y = design life of the landfill site, years

D = design or average depth* of the sanitary landfill (solid waste plus cover material), feet.

However, a larger site area than that given by equation (4) must be purchased to allow space for roads, fences, and facilities. Knowing the site utilization efficiency, E_s, the actual site area to be purchased, A_s, becomes:

$$A_s = A_f/E_s = v_f\, Y/E_s D \qquad (5)$$

Assuming a design life of Y = 10 years, design of D = 15 feet, and a site utilization efficiency of E_s = 0.85, along with the design utilization rate of 297 acre-feet/year, equation (5) yields a site area of 233 acres which the Eastern Appalachia region should purchase to accommodate the region's solid waste. The same result can be obtained using the nomographs in Appendix F which were constructed to graphically solve equations (3), (4), and (5). Based on the land requirement of 233 acres, the initial site purchase cost and site preparation expenses, assumed to be \$500/acre and \$175/acre, respectively, are summarized in Table 4.

Now, the average solid waste generation rate of 5.05 pounds/capita/day amounts to 420 tons/day to be received at the sanitary landfill. Assuming the landfill is operated five days per week, the average landfill operating rate becomes:

R = (7/5) (420 tons/day) = 588 tons/day.

Landfill equipment capabilities must be adequate to handle peak loads exceeding 588 tons/day.

* In using an average depth, D, it is assumed that the planes of the upper and lower surfaces of the completed sanitary landfill are parallel.

TABLE 4

SIZE-RELATED LANDFILL COSTS FOR REGIONAL SYSTEM
INVOLVING ONE SANITARY LANDFILL

Items	No. or Quantity	Unit Price	Initial Cost $	Estimated Life	Annual Cost $/Year
1. Land	233 acres	$500/ac	$116,500	10 years	$11,650
2. Site Preparation	233 acres	175/ac	40,800	10 years	4,080
3. Landfill Equipment Owning Cost					
(a) Dozer w/accessories	1	67,000	67,000	8000 hours	
(1) Depreciation	2080 hrs.yr	8.37/hr.	--	--	17,410
(2) Interest, Taxes, Insurance	2080	2.21/hr	--	--	4,597
(b) Crawler Loader w/accessory equipment	1	60,000	60,000	8000 hours	
(1) Depreciation	2080	7.50/hr	--	--	15,600
(2) Interest, Taxes, Insurance	2080	1.98/hr	--	--	4,118
4. Equipment Operating Cost					
(a) Dozer	2080	11.31/hr	--	--	23,525
(b) Crawler Loader	2080	12.00/hr	--	--	24,960
5. Salary of Additional Landfill Equipment Operator	1	6000/yr	--	--	6,000
6. Total			$284,300		$111,940

The sanitary landfill equipment assumed for estimating costs for the one-landfill alternative was as follows: one Allis Chalmers 21G crawler loader and one Allis-Chalmers HD 21 dozer.* Machinery with equivalent capabilities is available from other manufacturers. From the manufacturer's commercial literature, a combined maximum solid waste handling rate of 100 tons/hour was deduced. Assuming this equipment is operated at 75 percent of its maximum capability, average daily equipment operating time will be as follows:

$$\frac{588 \text{ tons/day}}{75 \text{ tons/hr}} = 7.84 \text{ hours/day or } \underline{8.0 \text{ hours/day}}$$

Accordingly, the approximate annual equipment operating time for each machine will be:

(8 hours/day) (5 days/week) (52 weeks/year) = 2080 hours/year.

According to two landfill equipment manufacturers, the hourly owning and operating costs for earthmoving and landfill machinery can be accurately estimated as a percentage of the total list price. For crawler loaders utilized under severe working conditions, the hourly costs expressed as a percent of the list price of the machine and attachments are approximately as follows: depreciation--0.0125 percent; interest, taxes, and insurance--0.0033 percent; operating expenses--0.0200 percent; and total wiring and operating costs--0.0360 percent. For dozers, the owning and operating cost factor for severe working conditions averages 0.325 percent of which the operating cost factor is 0.0169 percent.

Using the above cost information, the owning and operating costs for the one-landfill alternative were computed in Table 4. Combining the size-related sanitary landfill operating cost of C_{v1} =$111,940 from Tables 2 and 3 yields, from equation (2):

*Mention of commercial products does not imply endorsement by the U.S. Government.

$$T_s = \$20,990/yr + (1)\ (\$14,973/yr) + \$111,940/yr$$

$$T_s = \underline{\$147,903/yr}$$

or a unit cost of $0.96/ton based on the design solid waste quantity of 163,400 tons/year.

Sanitary landfill operating costs typically decrease with increasing landfill size.[8] Therefore, a solid waste management system involving only one landfill in the four-county region would be expected to reflect the least possible landfill operating cost, although transportation costs would be greatest for this alternative.

Three-landfill Alternative. For a regional solid waste disposal system involving three sanitary landfills, the four-county region was divided into the three subregions defined as follows. Subregion I included all of McDowell County and townships No. 1, 10, and 13 of Burke County (see Figures 2 and 3). Subregion III encompassed all of Alexander County and townships No. 6 and 13 of Caldwell County (Figures 4 and 5). Subregion II included the remainder of Burke and Caldwell Counties.

Following the same procedure given in the previous section, the land and equipment requirements for the three-landfill alternative were determined and are summarized in Table 5. The size-related sanitary landfill costs C_{v1}, C_{v2}, and C_{v3} are computed in Tables 6, 7, and 8. Combining these size-related costs with the fixed costs C_{fp} and C_{fs} from Tables 2 and 3 yields a total sanitary landfill operating cost of:

$$T_s = \$20,990/yr + (3\ \text{landfills})\ (\$14,973/yr/\text{landfill}) + (\$24,429 + 62,076 + 22,975)/yr.$$

$$T_s = \underline{\$175,389/yr}$$

or a unit solid waste disposal cost of $1.14/ton.

TABLE 5

LAND AND EQUIPMENT REQUIREMENTS FOR THREE-SANITARY LANDFILL SYSTEM

Subregion & Sanitary Landfill Ident.	Design Site Utilization Rate, V_f ac-ft/yr	Surface Area of Solid Waste Fill, A_f acres	Approx.Site Area to be Acquired, A_s Acres	Design Landfill Operating Rate, R (5-day wk) tons/da	Type of Sanitary Landfill Equipment Selected	Design Capability of Landfill Equipment (75% of max.) tons/hr.	Equipment Operating Time	
							Daily hrs/da	Annually hrs/yr
I	61.4	40.9	49	122	7G Crawler Loader	15.0	8.25	2140
II	178.5	119.0	140	354	21 G Crawler Loader	37.5	9.5	2450
III	57.0	37.9	45	113	7 G Crawler Loader	15.0	7.75	2020
TOTAL	296.9	197.8	234	589	---	---	---	--

TABLE 6

SIZE-RELATED LANDFILL COSTS FOR REGIONAL SYSTEM
INVOLVING THREE SANITARY LANDFILLS--
MC DOWELL AND WESTERN BURKE COUNTY LANDFILL

Item	No. or Quantity	Unit Price	Total Initial Cost	Estimated Life	Annual Cost $/Year
1. Land	49 acres	$500/ac	$24,500	10 years	$2450
2. Site Preparation	49 acres	175/ac	8,575	10 years	858
3. Landfill Equipment Owning Cost	1	27,565	27,565	8000 hrs	
(a) Depreciation	2140 hrs/yr	3.45/hr	--	--	7,383
(b) Interest, Taxes Insurance	2140 hrs/yr	0.91/hr	--	--	1,947
4. Equipment Operating Cost	2140 hrs/yr	5.51/hr	--	--	11,791
5. Total			$60,640		$24,429

TABLE 7

SIZE-RELATED LANDFILL COSTS FOR REGIONAL SYSTEM
INVOLVING THREE SANITARY LANDFILLS--
BURKE AND CALDWELL COUNTY LANDFILL

Item	No. or Quantity	Unit Price	Total Initial Cost	Estimated Life	Annual Cost $/Year
1. Land	140 acres	$500/ac	$70,000	10 yrs	$7,000
2. Site Preparation	140 acres	175/ac	24,500	10 yrs	2,450
3. Landfill Equipment Owning Cost	1	60,000	60,000	8000 hrs	
(a) Depreciation	2,450 hrs/yr	7.50/hr	--	--	18,375
(b) Interest, Taxes, Insurance	2,450 hrs/yr	1.98/hr	--	--	4,851
4. Equipment Operating Cost	2,450 hrs/yr	12.00/hr	--	--	29,400
5. Total			$154,500		$62,076

TABLE 8

SIZE-RELATED LANDFILL COSTS FOR REGIONAL SYSTEM
INVOLVING THREE SANITARY LANDFILLS--
ALEXANDER AND EASTERN CALDWELL COUNTY LANDFILL

	Item	No. or Quantity	Unit Price	Total Initial Cost	Estimated Life	Annual Cost $/Year
1.	Land	45 acres	$500/ac	$22,500	10 years	$2,250
2.	Site Preparation	45 acres	175/ac	7,875	10 years	788
3.	Landfill Equipment Owning Cost	1	27,565	27,565	8000 hours	
	(a) Depreciation	2020 hrs/yr	3.45/hr	--	--	6,969
	(b) Interest, Taxes, Insurance	2020 hrs/yr	0.91/hr	--	--	1,838
4.	Equipment Operating Cost	2020 hrs/yr	5.51/hr	--	--	11,130
5.	Total			$57,940		$22,975

Four-Landfill Alternative. The subregion boundaries for the four-landfill alternative were defined as being identical to the county borders for the following reasons. First, the county population and solid waste generation centers fall near the county seats of each county, as will be shown in a later analysis. The sanitary landfill should be located as closely as possible to the population centers. Secondly, the county seats appear to form the highway transportation hubs of their respective counties. Furthermore, political and public support for the project can be expected to be greater if known legal boundaries also serve as the solid waste subregion boundaries. Finally, if the proposed regional solid waste management authority should dissolve, each county would be left with a sanitary landfill already in operation.

The land and equipment requirements for the four-landfill alternative, determined in the previously described manner, are summarized in Table 9.

The size-related landfill costs, C_{vl}, are summarized in Tables 10, 11, 12, and 13. Using these values along with C_{fp} and C_{fs} from Tables 2 and 3 respectively in equation (2) yields a total sanitary landfill system operating cost of T_s = \$190,459/year which is equivalent to unit costs of \$1.24/ton.

TABLE 9

LAND AND EQUIPMENT REQUIREMENTS FOR FOUR-SANITARY LANDFILL SYSTEM

County & Sanitary Landfill Ident.	Design Site Utilization Rate, v_f ac-ft/yr	Surface Area of Solid Waste Fill, A_f acres	Approx. Site Area to be Acquired, A_s Acres	Design Landfill Operating Rate, R (5-day week) tons/day	Type of Sanitary Landfill Equipment selected	Design Capability of Landfill Equipment (75% of max.) tons/hr.	Equipment Operating Time	
							Daily hrs/da.	Annually hrs/yr.
McDowell Co.	49.8	33.3	40	99	7G Crawler Loader	15.0	6.75	1755
Burke Co.	106.6	71.0	84	212	21 G Crawler Loader	37.5	5.75	1495
Caldwell Co.	104.6	69.7	82	208	21 G Crawler Loader	37.5	5.75	1495
Alexander Co.	35.7	23.8	28	70	7G Crawler Loader	15.0	4.75	1235
Total	296.7	197.8	234	588	--	--	--	--

TABLE 10

SIZE-RELATED LANDFILL COSTS FOR REGIONAL SYSTEM INVOLVING FOUR SANITARY LANDFILLS--McDOWELL COUNTY LANDFILL

Item	No. or Quantity	Unit Cost	Initial Cost	Estimated Life	Annual Cost $/Year
1. Land	40 ac.	$500/ac	$20,000	10 years	$2,000
2. Site Preparation	40 ac.	175/ac	7,000	10 years	700
3. Landfill Equipment Owning Cost	1	27,565	27,565	8000 hours	
(a) Depreciation	1755 hrs/yr	3.45/hr	--	--	6,055
(b) Interest, Taxes, Insurance	1755 hrs/yr	0.91/hr	--	--	1,597
4. Equipment Operating Cost	1755 hrs/yr	5.51/hr	--	--	9,670
5. Total			$54,565		$20,022

TABLE 11

SIZE-RELATED LANDFILL COSTS FOR REGIONAL SYSTEM INVOLVING FOUR SANITARY LANDFILLS--BURKE COUNTY LANDFILL

Item	No. or Quantity	Unit Cost	Initial Cost	Estimated Life	Annual Cost $/Year
1. Land	84 ac.	$500/ac.	$42,000	10 years	$4,200
2. Site Preparation	84 ac.	175/ac.	14,700	10 years	1,470
3. Landfill Equipment Owning Cost	1	60,000	60,000	8000 hours	
(a) Depreciation	1495 hrs/yr	7.50/hr	--	--	11,213
(b) Interest, Taxes, Insurance	1495 hrs/yr	1.98/hr	--	--	2,960
4. Equipment Operating Cost	1495 hrs/yr	12.00/hr	--	--	17,940
5. Total			$116,700		$37,783

TABLE 12

SIZE-RELATED LANDFILL COSTS FOR REGIONAL SYSTEM INVOLVING FOUR SANITARY LANDFILLS--CALDWELL COUNTY LANDFILL

Item	No. or Quantity	Unit Price	Total Initial Cost	Estimated Life	Annual Cost $/Year
1. Land	82 ac.	$500/ac.	$41,000	10 years	$4,100
2. Site Preparation	82 ac.	175/ac.	14,350	10 years	1,435
3. Landfill Equipment Owning Cost	1	60,000	60,000	8000 hours	
(a) Depreciation	1495 hrs/yr	7.50/hr	--	--	11,213
(b) Interest, Taxes, Insurance	1495 hrs/yr	1.98/hr	--	--	2,960
4. Equipment Operating Cost	1495 hrs/yr	12.00/hr	--	--	17,940
5. Total			$115,350		$37,648

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TABLE 13

SIZE RELATED LANDFILL COSTS FOR REGIONAL SYSTEM INVOLVING FOUR SANITARY LANDFILLS--ALEXANDER COUNTY LANDFILL

Item	No. or Quantity	Unit Price	Total Initial Cost	Estimated Life	Annual Cost $/Year
1. Land	28 ac.	$500/ac	$14,000	10 years	$1,400
2. Site Preparation	28 ac.	175/ac.	4,900	10 years	490
3. Landfill Equipment Owning Cost	1	27,565	27,565	8000 hours	
(a) Depreciation	1235 hrs/yr	3.45/hr	--	--	4,261
(b) Interest, Taxes, Insurance	1235 hrs/yr	0.91/hr	--	--	1,124
4. Equipment Operating Cost	1235 hrs/yr	5.51/hr	--	--	6,849
5. Total			$46,465		$14,124

Five-Landfill Alternative. Annual costs to the four-county region for operating a system of five sanitary landfills were computed in the previously described manner. The five subregions were defined as follows:

Ident. of Subregion	Counties & Townships contained in Subregion *
I. McDowell County	All of McDowell County & Twp. 13 of Burke County
II. Central Burke County	Twps. 1, 2, 3, 8, 9, 10, 11, 12 of Burke County
III. Northern Caldwell County	Twps. 1, 2, 3, 4, 5, 7, 8, 9, 10 of Caldwell County
IV. Lake Rhodhiss Area	Twps. 4, 5,6, 7 of Burke County. Twps. 11, 12, 13 of Caldwell County
V. Alexander County	All of Alexander County and Twp. 6 of Caldwell County

* Township numbers correspond to those contained in Figures 2, 3, 4, & 5.

The land and equipment requirements developed for these subregions are shown in Table 14. The annual costs related to the size of the sanitary landfill are summarized in Tables 15, 16, 17, 18, and 19.

The total annual system operating cost for the five-sanitary landfill alternative, obtained by summing the total costs from Tables 2, 3, and 15 through 19, is T_s = \$220,438/year or \$1.44/ton. An even higher disposal system operating cost would result if more sanitary landfills were added.

Solid Waste Transportation Costs

In addition to the sanitary landfill system capital and operating costs just presented, selection of the optimum number and locations of sanitary landfills for the four-county Eastern Appalachia region was based on the cost of transporting solid waste from origin to disposal.

TABLE 14

LAND AND EQUIPMENT REQUIREMENTS FOR FIVE-SANITARY LANDFILL SYSTEM

Subregion & Sanitary Landfill Ident.	Design Site Utilization Rate, v_f ac-ft/yr	Surface Area of Solid Waste Fill, A_f acres	Approx. Site Area to be Acquired A_s Acres	Design Landfill Operating Rate, R (5-day week) tons/day	Type of Sanitary Landfill Equipment Selected	Design Capability of Landfill Equipment (75% of max.) tons/hr	Equipment Operating Time Daily hrs/day	Equipment Operating Time Annually hrs/yr
McDowell Co.	52.4	34.7	41	104	7 G Crawler Loader	15.0	7.0	1820
Central Burke Co.	66.3	44.3	53	132	12 G Crawler Loader	22.5	6.0	1560
Northern Caldwell Co.	68.3	45.5	54	136	12 G Crawler Loader	22.5	6.25	1625
Lake Rhodhiss Area	70.6	47.2	56	140	12 G Crawler Loader	22.5	6.25	1625
Alexander Co.	40.0	26.7	32	79	7 G Crawler Loader	15.0	5.5	1430
Total	297.6	198.4	236	591	---	--	--	--

TABLE 15

SIZE-RELATED LANDFILL COSTS FOR REGIONAL SYSTEM
INVOLVING FIVE SANITARY LANDFILLS--
McDOWELL COUNTY LANDFILL

	Item	No. or Quantity	Unit Price	Total Initial Cost	Estimated Life	Annual Cost $/Yr.
1.	Land	41 ac.	$500/ac.	$20,500	10 yrs	$2,050
2.	Site Preparation	41 ac.	175/ac.	7,175	10 yrs	718
3.	Landfill Equipment Owning Cost	1	27,565	27,565	8000 hours	
	(a) Depreciation	1820 hrs/yr	3.45/hr	--	--	6,279
	(b) Interest, Taxes, Insurance	1820 hrs/yr	0.91/hr	--	--	1,656
4.	Equipment Operating Cost	1820 hrs/yr	5.51/hr	--	--	10,028
5.	Total			$55,240		$20,731

TABLE 16

SIZE-RELATED LANDFILL COSTS FOR REGIONAL SYSTEM
INVOLVING FIVE SANITARY LANDFILLS--
CENTRAL BURKE COUNTY LANDFILL

Item	No. or Quantity	Unit Price	Total Initial Cost	Estimated Life	Annual Cost $/Year
1. Land	53 acres	$500/ac.	$26,500	10 years	$2,650
2. Site Preparation	53 acres	175/ac.	9,275	10 years	928
3. Landfill Equipment Owning Cost	1	44,430	44,430	8000 hours	
(a) Depreciation	1560 hrs/yr	5.56/hr	--	--	8,674
(b) Interest, Taxes, Insurance	1560 hrs/yr	1.52/hr	--	--	2,371
4. Equipment Operating Cost	1560 hrs/yr	8.84/hr	--	--	13,790
5. Total			$80,205		$28,413

TABLE 17

SIZE-RELATED LANDFILL COSTS FOR REGIONAL SYSTEM INVOLVING FIVE SANITARY LANDFILLS--NORTHERN CALDWELL COUNTY LANDFILL

Item	No. or Quantity	Unit Price	Total Initial Cost	Estimated Life	Annual Cost $/Year
1. Land	54 acres	$500/acre	$27,000	10 yrs	$2,700
2. Site Preparation	54 acres	175/acre	9,450	10 yrs	945
3. Landfill Equipment					
Owning Cost	1	44,430	44,430	8000 hours	
(a) Depreciation	1625 hrs/yr	5.56/hr	--	--	9,035
(b) Interest, Taxes, Insurance	1625 hrs/yr	1.52/hr	--	--	2,470
4. Equipment Operating Cost	1625 hrs/yr	8.84/yr	--	--	14,365
5. Total			$80,880		$29,515

TABLE 18

SIZE-RELATED LANDFILL COSTS FOR REGIONAL SYSTEM INVOLVING FIVE SANITARY LANDFILLS -- LAKE RHODHISS AREA LANDFILL

ITEM	No. or Quantity	Unit Price	Total Initial Cost	Estimated Life	Annual Cost $/Year
1. Land	56 acres	$500/ac.	$28,000	10 years	$2,800
2. Site Preparation	56 acres	175/ac.	9,800	10 years	980
3. Landfill Equipment Owning Cost	1	44,430	44,430	8000 hours	
(a) Depreciation	1625 hrs/yr	5.56/hr	--	--	9,035
(b) Interest, Taxes, Insurance	1625 hrs/yr	1.52/hr	--	--	2,470
4. Equipment Operating Cost	1625 hrs/yr	8.84/hr	--	--	14,365
5. Total			$82,230		$29,650

TABLE 19

SIZE-RELATED LANDFILL COSTS FOR REGIONAL SYSTEM INVOLVING FIVE SANITARY LANDFILLS--ALEXANDER COUNTY LANDFILL

	Item	No. or Quantity	Unit Price	Total Initial Cost	Estimated Life	Annual Cost $/Year
1.	Land	32 ac.	$500/ac.	$16,000	10 Years	$1600
2.	Site Preparation	32 ac.	175/ac.	5,600	10 Years	560
3.	Landfill Equipment Operating Cost	1	27,565	27,565	8000 Hours	
	(a) Depreciation	1430 hrs/yr	3.45/hr	--	--	4,934
	(b) Interest, Taxes Insurance	1430 hrs/yr	0.91/hr	--	--	1,301
4.	Equipment Operating Cost	1430 hrs/yr	5.51/hr	--	--	7,879
5.	Total			$49,165		$16,274

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The procedure for determing the optimal locations of centralized sanitary landfills and for calculating the regional solid waste transportation cost* for a given population distribution and sanitary landfill system alternative consisted of these steps:

1. Designation of a disposal site location within each subregion.
2. Summation of the annual distance of solid waste transportation from source centroid (i.e., township population centroid) to the assumed disposal site location.
3. Repetition of steps 1 and 2 until a minimum value of the total annual waste transport distance within the region was approached.
4. Computation of the total annual transportation costs from the minimized travel distance and unit haul costs for selected vehicle types.

Using this procedure the solid waste transportation costs to the Eastern Appalachia region residents were computed for these situations:

1. Theoretical situation in which all householders haul their own waste.
2. Present situation in which organized collection is provided to 62 percent of the residents (1968 estimate), while the remaining 38 percent transport their own waste.
3. Proposed system utilizing present municipal and private collection services but providing rural bulk-container collection service to 60-65,000 rural residents.

*The term "transportation costs" as used in this analysis excludes the costs of house-to-house collection and crew relief time which are essentially independent of sanitary landfill location.

Optimum Location of Sanitary Landfills. For each number of regional sanitary landfills assumed (N = 1, 3, 4, 5) the boundaries of the subregions or "solid waste shed areas" defined previously were retained. Within each subregion containing "j" townships, the optimum location of the sanitary landfill was approximately determined by the trial and error process of minimizing the following function:

$$\sum_j \frac{p_j x_j}{p_t}$$

Where P_t = total population in the subregion

p_j = population of the j^{th} township in the subregion

x_j = actual one-way travel distance from the township population centroid to the assumed landfill location, miles

In effect, the landfill location which produced the smallest total of township centroid-to-disposal site distances, weighted according to township population, was taken as the optimum landfill location.

The optimum sanitary landfill site location determined by this procedure usually lay within or near the city limits of the major city within each subregion, as shown in Figure 6. The actual landfill sites selected should be located as near as possible to these optimum locations. Actual site selection and sanitary landfill design would require a separate, detailed study beyond the scope of the present analysis.

Cost of Self-Transport of Solid Waste. The overall regional transportation cost was determined for the theoretical situation in which each family, consisting of 3.6 persons[5], was assumed to haul its own solid waste to the nearest optimally located sanitary landfill once per week. For each township, the accumulated annual travel distance

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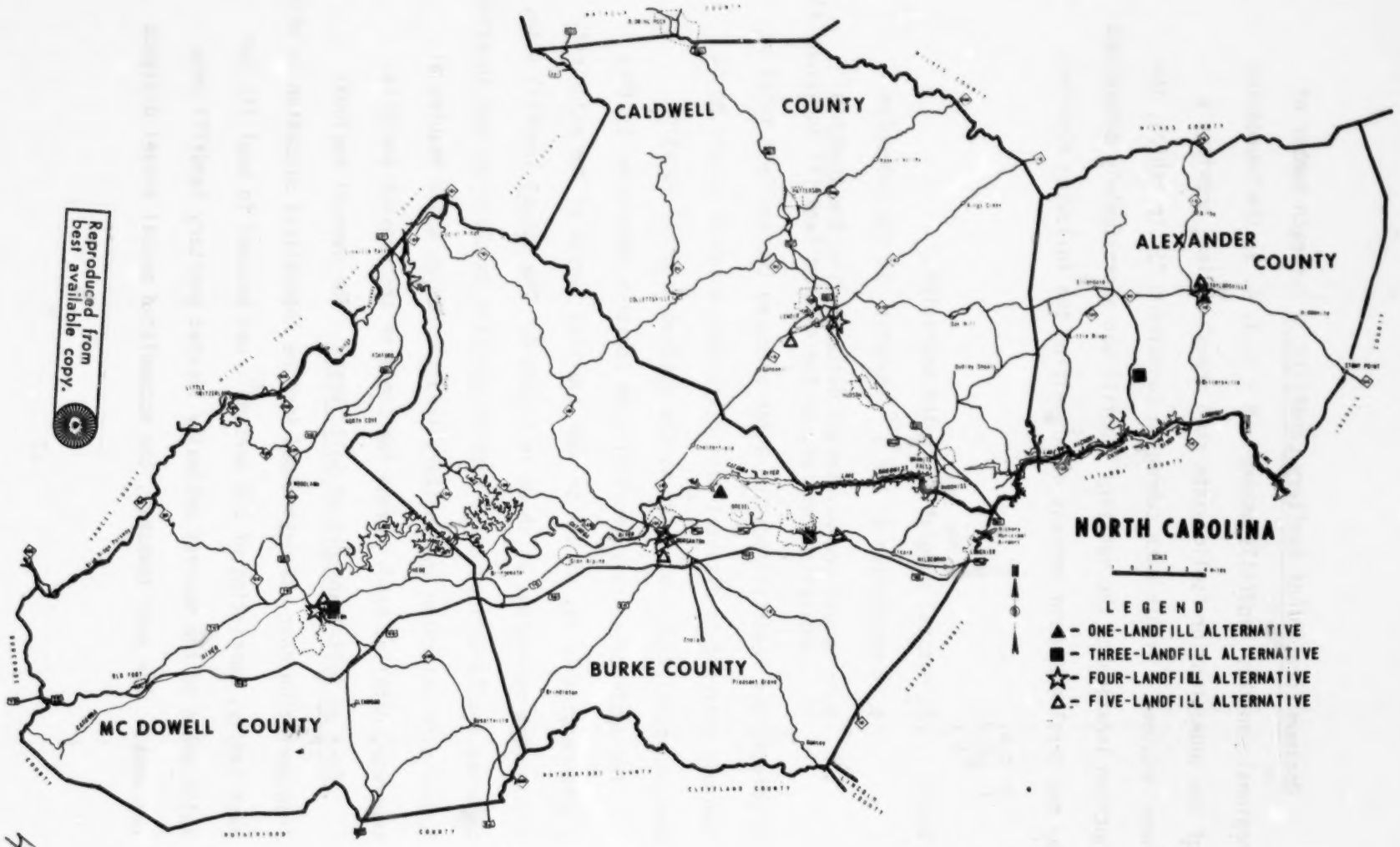

Figure 6. Optimal locations of sanitary landfills for alternative numbers of landfills.

was calculated as the product of (a) the roundtrip distance from the township population centroid tc the disposal site, (b) the number of families in the township (i.e. population/3.6), and (c) the annual number of trips to the landfill per household (i.e., 52 trips/year). For each alternative number of sanitary landfills, the total annual travel distance involved for the four-county region was determined by summing the accumulated distance for the 44 townships. Finally, the regional transportation cost was computed by applying a unit cost factor of $0.10/mile to the total annual mileage. Thus, the total cost to the four-county region for self-transport of solid waste, T_t, was:

$$T_t = \frac{fC_x}{} \sum_{j=1}^{44} 2\, x_j p_j \qquad (6)$$

In which = collection frequency, collection events/year

pd = average family size, persons/household

C_x = unit transportation cost, $/mile

p_j = population of j^{th} township in the subregion

x_j = one-way travel-distance from township population centroid to assumed landfill location, miles

The resulting costs calculated from equation (6) are summarized in Table 20. Note the drastic decrease in unit transportation cost with increases in the number of disposal sites.

Transportation Costs For Present Collection Systems. This solid waste transportation alternative, involving organized collection in "urban" areas and self-transport of waste in "rural" areas, represents the present collection situation. The unit costs of transporting solid waste between the township centroids and the disposal sites were estimated using the 1970 township population statistics reported in Table 1 and Appendix A.

TABLE 20

COST OF SELF-TRANSPORT OF SOLID WASTES

Number of Regional Sanitary Landfills	Total Annual Cost to Residents $/Year	Average Unit Solid Waste Transportation Cost	
		$/Ton	$/Person/Year
1	$8,970,000	$58.34	$53.67
3	4,720,000	30.67	28.22
4	2,560,000	16.62	15.29
5	2,310,000	15.02	13.82

Transportation costs for essentially urban townships, or fractions thereof, which were known or assumed to have organized solid waste collection (see Appendix D, Table D-1) were computed in the following manner. First, the fraction of township populations served by organized collection were estimated as shown in Table 21. Then, using the urban solid waste generation rate of 6.96 lbs/capita/day, the number of truckloads of solid waste to be collected was computed. Next, the distance from the urban township centroids to the nearest optimally located sanitary landfill was multiplied by the applicable annual number of truckloads. These township distances were summed over the entire region to yield the total annual mileage driven.

Finally, the cost of transportation was evaluated at $0.52/vehicle-mile.[9] This value includes fuel, repairs, vehicle maintenance and depreciation, and labor* for the transportation phase only. It excludes the time-related costs of house-to-house collection and crew relief time which typically account for the majority of the total municipal collection and transportation cost but which are virtually independent of sanitary landfill location.

This procedure for computing costs of transporting urban solid wastes can be summarized mathematically as follows:

$$T_{tu} = \frac{365\, P_{cdu} C_x}{\gamma_{tc} V_t} \sum_{j=1}^{44} 2x_j p_{ju} \qquad (7)$$

---

*Labor costs were estimated for a two-man crew, paid a $3/hour wage, riding in the collection vehicle traveling at 20 miles/hour (average). Thus, labor costs amounted to $0.30/mile.

TABLE 21

ALLOCATION OF ORGANIZED COLLECTION SERVICES TO TOWNSHIPS

County and Township	1970 Population	Assumed Fraction of Population Served by Organized Collection	Population Having Organized Collection
Alexander County			
5. Taylorsville Twp.	7,063	1.00	7,063
Burke County			
5. Drexel Twp.	4,563	1.00	4,563
6. Lovelady Twp.	6,630	1.00	6,630
7. Icard Twp.	11,040	0.70	7,728
10. Silver Creek Twp.	5,555	0.50	2,778
11. Morganton Twp.	22,389	1.00	22,389
Caldwell County			
7. Lower Creek Twp.	10,619	0.70	7,433
8. Lenoir Twp.	16,979	0.80	13,583
11. North Catawba Twp.	3,760	1.00	3,760
12. Hudson Twp.	8,041	1.00	8,041
13. Lovelady Twp.	8,536	0.90	7,682
McDowell County			
2. Nebo Twp.	2,978	0.60	1,787
9. Old Fort Twp.	4,399	0.60	2,639
10. Marion Twp.	14,624	0.70	10,237
Total			106,313

in which

T_{tu} = annual cost of transporting urban solid waste in compactor collection vehicles, $/year

P_{cdu} = urban solid waste generation rate, lbs/capita/day

γ_{tc} = unit weight of moist compacted refuse in collection vehicle, lbs/cu yd

V_t = Collection vehicle capacity, yds^3

p_{ju} = population of the j^{th} township served by organized collection

The variables C_x and X_j were defined previously in connection with equation (6). Values of γ_{tc} and V_t assumed for this analysis were 500 lbs/cu yd and 16 cu yd, respectively.

For the rural population not served by organized solid waste collection, the cost of self-transport of solid waste was evaluated using equation (6). Into this equation, the rural population of each township, $p_{jr} = (p_j - p_{ju})$ was substituted for p_j and the rural transportation cost $T_{tr} = (T_t - T_{tu})$ was substituted for T_t. Other values used in this equation were the same as those assumed in the previous analysis of self-transport costs.

The rural and urban solid waste transportation costs thus computed using equations (6) and (7) are given in Table 22. Three important trends can be seen from this data. First, regional solid waste transportation costs decrease markedly when the number of regional sanitary landfills is increased from one to four. However, little or no further reduction in transportation costs can be expected to result from establishment of more than four landfills. Finally, self-transport of rural solid waste appears to be about 50 times more costly per ton of waste

TABLE 22

REGIONAL SOLID WASTE TRANSPORTATION COSTS

UTILIZING PRESENT COLLECTION SYSTEMS

Number of sanitary landfills	Cost for urban solid waste		Cost for rural solid waste		Total solid waste transportation cost		
	$/yr (x1000)	$/ton	$/yr (x1000)	$/ton	$/yr (x1000)	$/ton	$/person
1	551	4.08	4,160	184.50	4,710	30.60	28.20
3	314	2.32	1,970	87.60	2,290	14.90	13.70
4	142	1.05	1,310	58.40	1,460	9.47	8.71
5	110	0.81	1,350	59.90	1,460	9.48	8.72

handled than solid waste transportation using compaction vehicles. This high cost of rural solid waste handling is attributable to far lower vehicular efficiencies and to longer haul distances to sanitary landfills.

With the present collection situation, 89 percent of the total regional solid waste transportation cost would be contributed by the 38 percent of the population without organized collection service. This inequity probably accounts in part for the large number of general use and promiscuous open dumps in the region. Further, it illustrates the fact that enforcement of backyard burning and open dumping ordinances will be exceedingly difficult unless regular solid waste collection service is extended to these rural residents.

Transportation Costs with Rural Collection System. The advantages of providing bulk container solid waste collection service to rural residents are obvious. If an adequate number of containers were provided, no family would have to drive more than 5 miles (one-way) to dispose of its solid waste, instead of the 20-mile distance encountered with centralized sanitary landfills but without a bulk collection system. Costs would be expected to decline sharply because the accumulated annual travel distance involved would be drastically reduced, although labor and capital costs of the rural collection system would partially offset this cost advantage.

An analysis was performed to determine representative operating and capital costs of a rural bulk container solid waste collection system, adequately sized to serve those residents currently without organized collection. To provide a basis for comparing the regional transportation costs of this system with previous analyses, the cost per ton for hauling refuse from rural township centroids to disposal sites using a bulk collection system was computed for the three-, four-, and five-sanitary landfill

alternatives. The cost of transporting urban solid waste collected by existing public and private collectors would be unaffected by introducing the rural collection system. The method of computing urban costs, summarized in equation (7), was previously described.

The annual transportation cost of operating a bulk collection system serving rural areas was estimated using the basic form of equation (7) as follows:

$$T_{tr} = \frac{365\ P_{cdr}\ C_x}{\gamma_{tc}\ V_t} \sum_{j=1}^{44} 2x_j\ p'_{jr} \qquad (8)$$

wherein p'_{jr} is the rural township population augmented by the applicable population equivalent for recreational solid waste generation as reported in Appendix E. Other values assumed for this analysis were derived mainly from data compiled from the Chilton County, Alabama rural solid waste collection demonstration project.[10,11] These values were as follows: P_{cdr} = 1.00 lbs/capita/day, c_x = \$0.78/mile*, γ_{tc} = 440 lbs/cu yd, and V_t = 25 cu yds.

Now, equation (8) probably underestimates the total mileage and cost which dould be incurred in an actual bulk collection system. Reasons for this are as follows. First, there is no way to include the capital costs of bulk containers and container site preparation in equation (8). Moreover, the collection vehicles would sometimes travel to the disposal site only partially loaded, thereby necessitating more loads. Similarly, only an integer number of vehicles can be purchased so that some vehicle capacity made available might not actually be utilized. Also, many more miles would be driven within townships in collecting from containers than was reflected in the foregoing procedure. On the contrary, the use of collection

* The Chilton County project reported average costs for labor, equipment, operation, and depreciation of \$9.33/operating hour over a 29 month period. Assuming an average vehicular speed of 12 miles/hr including collection stops, the value of C_x = \$0.78/mile was derived.

routes which interconnect outlying townships, which would be the case in a real system application, would tend to shorten the overall distances traveled. Furthermore, many residents living nearer the sanitary landfills than the nearest bulk container (5 miles maximum) may choose not to utilize the bulk containers.

Based on the above reasoning, it was decided to double the round trip population-centroid-to-landfill distances to more accurately reflect distances traveled and costs encountered in an actual situation. Because of the subjectivity involved, however, the resulting transportation cost estimates, T_{tr}, are only useful for determining the optimum number of sanitary landfills, and not for budgetary purposes.

The final results of this transportation cost analysis for the proposed solid waste collection system, involving the retention of all present organized collection services and initiation of a rural bulk container collection system, are presented in Table 23. The unit costs in the last column of Table 23 were averaged over the entire population of the four-county region. The urban collection systems would incur significantly lower transportation costs ($0.81-$2.32/ton) than the weighted average of $1.09-$2.64/ton. The rural collection system on the other hand, would cost considerably more than the average ($4.28-$6.30/ton).

For a regional solid waste disposal system consisting of four sanitary landfills, the rural population (38 percent of the total) would account for roughly 30 percent of the total regional solid waste transportation cost if the rural collection system were fully implemented, This cost distribution is far more equitable than was the previous situation without collection service to rural residents. The equipment and budgetary requirements for the rural bulk container collection system are developed in Appendix G.

TABLE 23

ESTIMATED TRANSPORTATION COSTS FOR URBAN AND RURAL

COLLECTION SYSTEMS WITH VARYING NUMBERS OF SANITARY LANDFILL

Number of sanitary landfills	Unit transportation cost for urban solid waste $/ton	Unit transportation cost for rural solid waste $/ton	Total regional transportation cost $/ton
3	2.32	6.30	2.64
4	1.05	4.28	1.30
5	0.81	4.39	1.09

Summary of Transportation Cost Analysis. The unit cost of transporting solid waste by the three modes considered are summarized in Table 24. The fictitious case involving self-transport of all solid waste was used to define the maximum limit of transportation costs for each alternative number of sanitary landfills. When the existing public and private collection systems were taken into account, the average transportation costs were approximately halved. Implementation of a rural bulk container solid waste collection system would reduce regional solid waste transportation costs even more markedly. For instance, in the case of the four-landfill alternative, urban solid waste transportation costs would remain the same as they presently are ($1.05/ton) while the rural solid waste transportation costs would be drastically decreased from $58.35/ton to $4.28/ton. Hence, the obvious conclusion to be drawn from the transportation cost analysis is that a rural solid waste collection system, sized as shown in Appendix G, should be implemented within the four-county study region.

TABLE 24

COMPARISON OF SOLID WASTE TRANSPORTATION COSTS FOR VARIOUS TRANSPORTATION METHODS

Number of Sanitary Landfills	Cost of Self-transport of Solid Wastes $/Ton	Average Transportation Cost With Present Collection Systems but without Rural Bulk Collection $/Ton	Average Transportation Cost with Present Collection Systems and Rural Bulk Collection $/Ton
1	58.34	30.60	--
3	30.67	14.87	2.64
4	16.62	9.47	1.30
5	15.02	9.48	1.09

SELECTION OF DISPOSAL SYSTEM ALTERNATIVE

The determination of the most economical number of sanitary landfills to be established in the four-county Eastern Appalachia Health Region was based on the criterion of minimizing the combined unit costs of sanitary landfill operation and solid waste transportation. Developed in detail in the foregoing sections, transportation and disposal costs are summarized in Table 25 and Figure 7.

For all practical purposes, there appears to be no difference in cost between the four-and five-landfill alternatives. Advantages to be derived from establishing four sanitary landfills instead of five include enhanced local support for the new project (because each county would in effect contain a landfill) and easier management of personnel by the project director. It is therefore recommended that the Eastern Appalachia Health Region install four sanitary landfills located approximately as shown in Figure 6. Budgetary requirements for the four-sanitary landfill alternative were developed in Tables 2, 3, 9, 10, 11, 12,and 13 and Appendix G.

TABLE 25

COMBINED REGIONAL COSTS OF SANITARY LANDFILL OPERATION AND SOLID WASTE TRANSPORTATION

Number of Sanitary Landfills	Total Project Cost for Sanitary Landfills $/Ton	Total Regional Cost for Solid Waste Transportation $/Ton	Combined Regional Cost for Transportation and Disposal $/Ton
1	$0.96	--	--
3	1.14	$2.64	$3.78
4	1.24	1.30	2.54
5	1.44	1.09	2.53

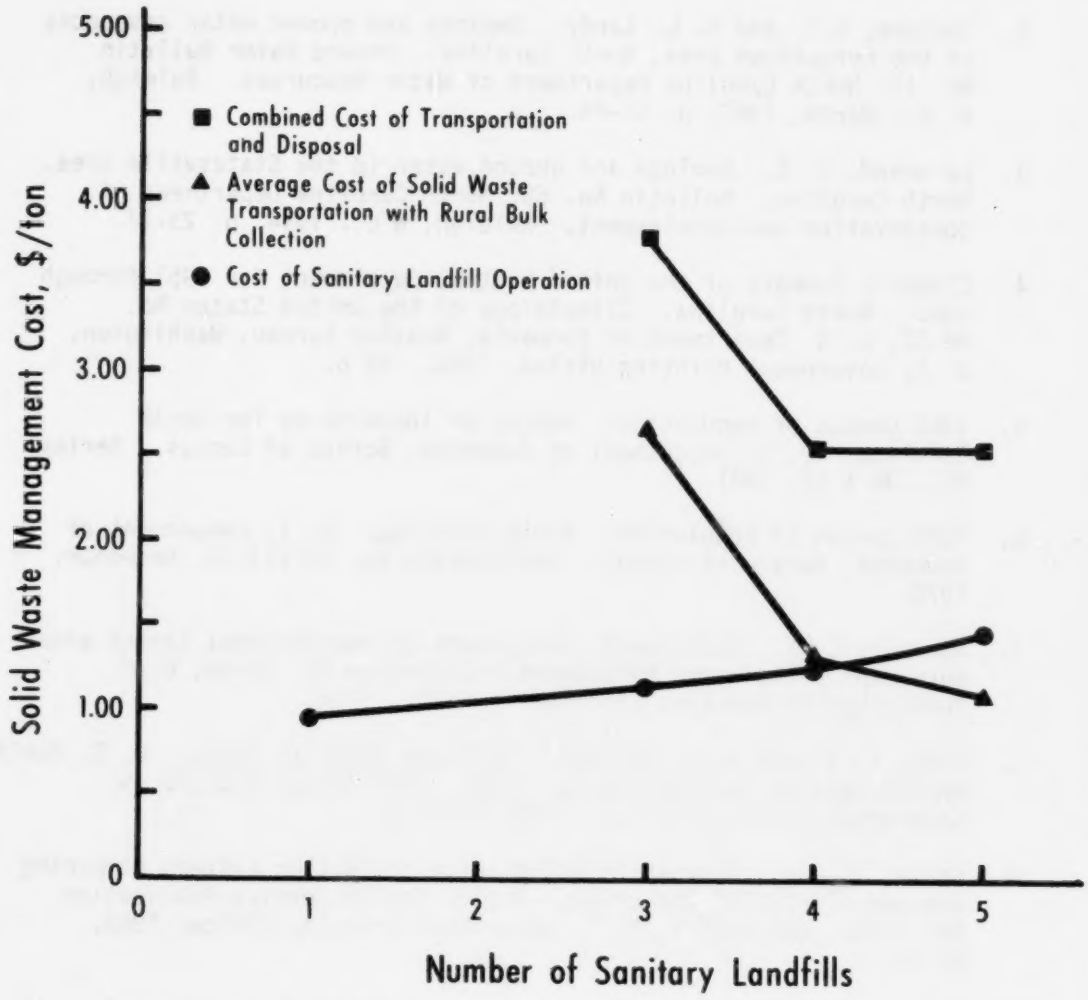

Figure 7. Comparision of total regional cost for transportation and disposal of solid waste for various numbers of sanitary landfills

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APPENDIX A

POPULATIONS OF COUNTIES AND TOWNSHIPS WITHIN THE EASTERN APPALACHIA HEALTH REGION NORTH CAROLINA

TABLE A-1

POPULATIONS OF COUNTIES AND TOWNSHIPS WITHIN THE EASTERN APPALACHIA HEALTH REGION, NORTH CAROLINA

County or Township	Population in Census Years			
	1940	1950	1960	1970
A. Alexander County	13,454	14,534	15,625	19,466
1. Little River Twp.	704	767	500	537
2. Sugar Loaf Twp.	950	897	858	796
3. Gwaltneys Twp.	1,441	1,421	1,257	1,382
4. Sharpes Twp.	2,476	2,640	2,764	3,092
5. Taylorsville Twp.	3,892	4,813	5,810	7,063
6. Ellendale Twp.	1,539	1,482	1,892	2,173
7. Wittenburg Twp.	1,629	1,821	1,906	3,614
8. Millers Twp.	823	713	638	809
B. Burke County	38,615	45,518	52,701	60,364
1. Jonas Ridge Twp.	625	572	457	488
2. Upper Creek Twp.	814	609	508	753
3. Lower Creek Twp.	1,054	1,004	1,168	1,389
4. Smokey Creek Twp.	286	284	229	442
5. Drexel Twp.	2,448	2,414	2,594	4,563
6. Lovelady Twp.	5,218	6,414	7,010	6,630
7. Icard Twp.	5,071	7,080	8,692	11,040
8. Lower Fork Twp.	1,276	1,280	1,417	1,722
9. Upper Fork Twp.	699	644	1,349	815
10. Silver Creek Twp.	3,406	3,844	4,394	5,555
11. Morgantown Twp.	15,371	18,088	21,274	22,389
12. Quaker Meadow Twp.	1,208	2,045	2,277	3,500
13. Linville Twp.	1,139	1,220	1,282	1,078

TABLE A-1 Cont'd.

County or Township	Population in Census Years 1940	1950	1960	1970
C. Caldwell County	35,795	43,352	49,552	56,699
1. Globe Twp.	736	492	305	292
2. Mulberry Twp.	705	753	1,062	730
3. Patterson Twp.	1,626	1,965	2,108	2,202
4. Yadkin Valley Twp.	1,134	1,060	1,008	1,041
5. Kings Creek Twp.	1,202	1,377	1,360	1,055
6. Little River Twp.	1,693	2,060	1,994	2,337
7. Lower Creek Twp.	6,353	8,437	10,007	10,619
8. Lenoir Twp.	11,776	14,255	15,609	16,979
9. Johns River Twp.	1,067	956	932	1,047
10. Wilson Creek Twp.	45	97	107	60
11. North Catawba Twp.	982	1,781	2,405	3,760
12. Hudson Twp.	2,492	3,363	5,240	8,041
13. Lovelady Twp.	5,922	6,756	7,477	8,536
D. McDowell County	22,996	25,720	26,742	30,648
1. North Cove Twp.	1,661	1,550	1,174	1,242
2. Nebo Twp.	1,157	1,638	1,897	2,978
3. Higgins Twp.	574	767	1,236	1,522
4. Dyartsville Twp.	823	832	920	993
5. Brackett Twp.	264	200	166	135
6. Glenwood Twp.	659	928	942	1,059
7. Montford Cove Twp.	745	954	1,543	1,930

TABLE A-1, Cont'd

County or Township	Population in Census Years			
	1940	1950	1960	1970
8. Crooked Creek Twp.	1,221	1,238	1,621	1,766
9. Old Fort Twp.	3,364	3,582	3,956	4,399
10. Marion Twp.	12,534	14,031	13,287	14,624
E. Total	110,860	129,114	144,620	167,177

APPENDIX B

POPULATIONS OF MUNICIPALITIES WITHIN THE EASTERN APPALACHIA HEALTH REGION NORTH CAROLINA

TABLE B-1

POPULATIONS OF MUNICIPALITIES WITHIN
THE EASTERN APPALACHIA HEALTH REGION
NORTH CAROLINA

County or City	Population in Census Years			
	1940	1950	1960	1970
A. Alexander County				
1. Taylorsville	1,222	1,310	1,470	1,231
2. Stoney Point (Uninc.)	--	1,020	1,015	1,001
B. Burke County				
1. Drexel	881	988	1,146	1,431
2. Glen Alpine	665	695	734	797
3. Hildebran	337	529	518	481
4. Morgantown	7,670	8,311	9,186	13,625
5. Rhodhiss (Burke Co.)	321	336	328	312
6. Valdese	2,615	2,730	2,941	3,182
C. Caldwell County				
1. Granite Falls	1,873	2,286	2,644	2,388
2. Hudson	748	922	1,536	2,820
3. Lenoir	7,598	7,888	10,257	14,705
4. Mortimer	42	13	3	27
5. Patterson	158	195	265	344
6. Rhodhis (Caldwell Co.)	609	587	509	472
D. McDowell County				
1. East Marion-Clinchfield (uninc.)	--	2,901	2,442	3,015
2. Marion	2,889	2,740	3,345	3,335
3. Old Fort	774	771	787	676
4. West Marion (uninc.)	--	1,233	2,335	3,034

APPENDIX C

LOCATION AND OWNERSHIP OF EXISTING LAND DISPOSAL SITES IN EASTERN APPALACHIA HEALTH REGION

TABLE C-1

EXISTING GENERAL USE LAND DISPOSAL SITES
IN THE EASTERN APPALACHIA HEALTH REGION

Name of Land Disposal Site	Estimated Quantity* of Solid Waste Delivered To Site - Tons/Yr	Type of Site Ownership	
		Public	Private
1. Old Fort	679	x	
2. Little Switzerland	87	x	
3. Marion	20,043	x	
4. Linville Falls	9	x	
5. Dysartsville Comm.	457	x	
6. Glen Alpine	130	x	
7. Morganton	25,740	x	
8. Drexel	651	x	
9. Valdese	725	x	
10. Hilton's Refuse Disp.	3,536		x
11. Granite Falls	9,360	x	
12. Rhodhiss	1,872	x	
13. Hildebran	3,015	x	
14. Henry River Comm.	1,350	x	
15. Bristal Creek Comm.	407	x	
16. Anderson Refuse Disp.	467		x
17. Skew Refuse Disp.	416		x
18. Lenoir	38,835	x	
19. Garner Refuse Disp.	1,092		x
20. Chester Refuse Disp.	624		x
21. Blowing Rock	3,239†	x	
22. Walsh Refuse Disp.	3,120		x
23. Sanitary Pick-up Service	18,720		x
24. Taylorsville	6,240	x	
Totals	137,575	17	7

* Data from the 1968 North Carolina survey of community solid waste management practices.

† This refuse is collected in Watauga County.

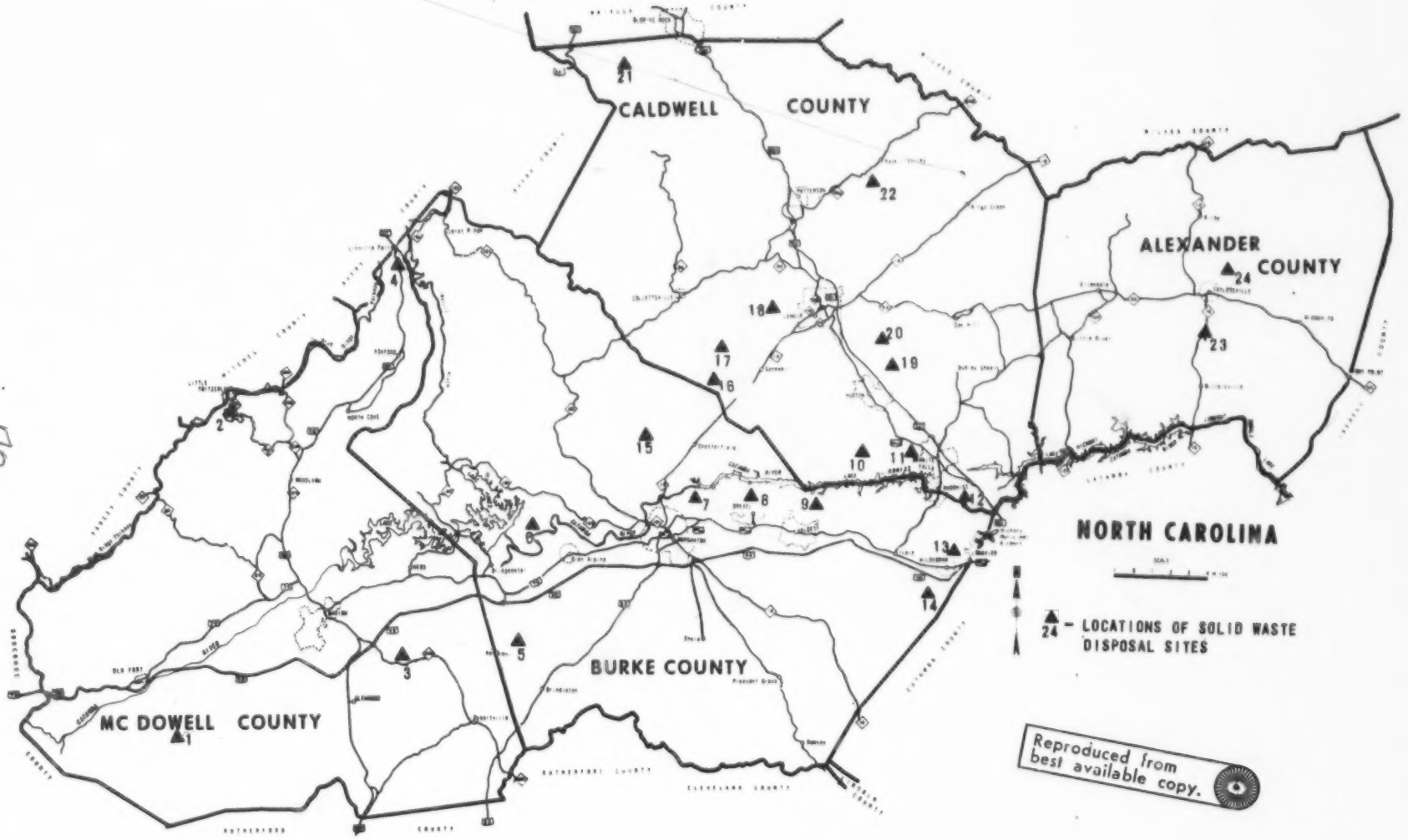

Figure C-1. Locations of existing general use land disposal sites in the Eastern Appalachia Region.

APPENDIX D

MUNICIPALITIES OPERATING PUBLIC SOLID WASTE COLLECTION SYSTEMS

TABLE D-1

MUNICIPALITIES OPERATING PUBLIC SOLID WASTE COLLECTION SYSTEMS

Municipality	County	1970 Population	No. of Collection Vehicles *	
			Compactor† Trucks	Non-Compactor† Trucks
Taylorsville	Alexander	1,231	3	1
Morganton	Burke	13,625	3	3
Valdese	Burke	3,182	2	1
Drexel	Burke	1,431	1	1
Glen Alpine	Burke	797	1	1
Hildebran	Burke	481	1	1
Lenoir	Caldwell	14,705	3	2
Granite Falls	Caldwell	2,388	1	2
Hudson	Caldwell	2,820	1	1
Marion	McDowell	3,335	2	2
Old Fort	McDowell	676	1	1
Total		44,671	19	16

* Unpublished data from North Carolina State Health Department, Sanitary Engineering Division, 1970.

† Actual vehicle capacities are unavailable.

APPENDIX E

CALCULATION OF RECREATIONAL SOLID WASTE QUANTITY

TABLE E-1

EXTENT OF RECREATIONAL USE OF DUKE POWER COMPANY'S PROPERTY IN EASTERN APPALACHIA REGION *

Recreational Area	No. Day-Use Visits		No. Overnight Visits	
	Annual Visits	Av. Peak Weekend Day‡	Annual Visits	Av. Peak Weekend Day ‡
	Visitor-days/ year	Visitor-days/ year	Camper-days/ year	Camper-days/ year
Lake Rhodhiss	257,000	3,400	8,000	100
Lake Hickory †	706,000	9,600	226,000	2,900
Lake James	292,000	4,700	37,000	500

*Data from Duke Power Company, Environmental Health Section, Charlotte, North Carolina, 1968.

† Approximately one-half of these visits occurred in Catawba County.

‡ These values reflect the average visits/day that occurred during the peak weekend and/or holiday visitation period.

TABLE E-2

SOLID WASTE GENERATED AT
LAKES RHODHISS, HICKORY, AND JAMES BY RECREATIONAL USERS

Recreational Area	Average Amounts † of Solid Waste Generated by:			
	Day-Use Visits tons/yr	Overnight Visits tons/yr	Private Cottages tons/yr	Total Tons/yr
Lake Rhodhiss	123	5	4	132
Lake Hickory*	169	71	64	304
Lake James	188	23	16	227
Totals	480	99	84	663

* The solid waste produced by recreational users in Catawba County, assumed to be one-half the total amount from the Lake Hickory recreational area, is not included.

† The following solid waste generation rates in recreational areas were determined by Spooner:[7]

(a) Day use visits--0.96 lbs/visitor-day
(b) Overnight stays--1.26 lbs/camper-day
(c) Private cottage occupants--2.13 lbs/occupand-day

TABLE E-3

DISTRIBUTION OF RECREATIONAL SOLID WASTE
ACCORDING TO COUNTIES AND TOWNSHIPS BORDERING
DUKE POWER COMPANY LAKES

County & Township	Township Number*	Name of Recreation Area	Estimated Percent of Solid Waste from Recreational areas† %	Solid Waste Quantity Allocated Tons/yr	Rural Population Equivalents‡ Persons/yr
Alexander County					
Wittenburg Twp.	7	Lake Hickory	85	258	705
Burke County					
Linville Twp.	13	Lake James	80	182	498
Smokey Creek Twp.	4	Lake Rhodhiss	10	13.2	36
Drexel Twp.	5	Lake Rhodhiss	10	13.2	36
Lovelady Twp.	6	Lake Rhodhiss	10	13.2	36
Icard Twp.	7	Lake Rhodhiss	10	13.2	36
Caldwell County					
N. Catawba Twp.	11	Lake Rhodhiss	30	39.5	108
Lovelady Twp.	13	Lake Rhodhiss	30	39.5	108
Lovelady Twp.	13	Lake Hickory	15	46.0	125
McDowell County					
Nebo Twp.	2	Lake James	20	45.0	123
			Total	662.8	1811

* Township numbers correspond to those in Figures 2, 3, 4, & 5.

† Percentages were estimated on the basis of shoreline length and locations of access roads, public access areas, and private cottages.

‡ Computed using a solid waste generation rate of 2.0 lbs/capita/day for rural residents.

APPENDIX F

NOMOGRAPHS FOR CALCULATING SANITARY LANDFILL AREA AND VOLUME REQUIREMENTS

APPENDIX F

NOMOGRAPHS FOR CALCULATING SANITARY LANDFILL AREA AND VOLUME REQUIREMENTS

Sanitary Landfill Capacity Requirements

The design rate of utilization of sanitary landfill volume can be computed from the following relationship:

$$v_f = \frac{(365 \text{ days/yr})\ (27\ \frac{ft^3}{yd^3})\ P_{cd} r\ p}{(43{,}560\ \frac{ft^3}{ac\text{-}ft})\ \gamma_{fc}} = \frac{P_{cd} e\ p}{4.42\ \gamma_{fc}} \qquad (1)$$

in which: v_f = design rate of utilization of landfill volume, acre-ft/yr

p = design population

P_{cd} = solid waste generation rate, lbs/capita-day

r = ratio of the volume of compacted refuse and cover material in the completed landfill to the volume of compacted refuse only

γ_{fc} = unit weight of compacted moist refuse in completed landfill, lbs/cu yd

The landfill surface area to be actually utilized, A_f, can be obtained from the following expression:

$$A_f = v_f\ Y/D \qquad (2)$$

where Y = design life of the landfill site, years

D = design average depth of sanitary landfill (solid waste plus cover material), feet

To allow space for roads, fences, facilities and equipment storage, a larger site area than that given by equation (4) must be purchased. Knowing the site utilization efficiency, E_s, the actual site area to be purchased, A_s, becomes:

$$A_s = A_f/E_s = v_f\ Y/E_s\ D \qquad (3)$$

Nomographs for Sizing Sanitary Landfills

The average rate of utilization of sanitary landfill volume was expressed as equation (1) which can be expeditiously solved for v_f using the nomograph in Figure F-1. Equation (3) has been presented graphically as Figure F-2, which can be used to determine the actual site area required, A_s.

As an example of the use of these nomographs, the landfill volumetric utilization rate, v_f, and site area, A_s, are determined assuming the following parameters:

P_{cd} = 5.00 lb/capita day Y = 10 years

p = 58,800 persons D = 15 feet

fc - 750 lbs/cu yd E_s = 0.85

r = 1.20 (i.e., cover: refuse volume = 1:5)

In Figure F-1, proceeding from left to right, a straight line intersecting the given values of P_{cd} and p produces an annual solid waste tonnage of 54 tons/yr. A line through this value and the solid waste density of 750 lbs/cu yd yields an annual compacted solid waste volume of 140 cu yd/yr or 88 ac-ft/yr. Finally, projecting this value of compacted refuse volume through r = 1.20 results in a design landfill utilization rate of v_f = 110 ac-ft/yr.

Then in Figure F-2, a straight line projected through v_f = 110 acre-ft/yr and Y = 10 years bisects the required landfill capacity axis at 1100 ac-ft. In a similar fashion, dividing graphically by D=15 ft gives A_f = 73 acres, which then alighed with E_s = 0.85 projects to A_s = 86 acres. By comparison, the site area calculated from equation (1) was A_s = 84.4 acres.

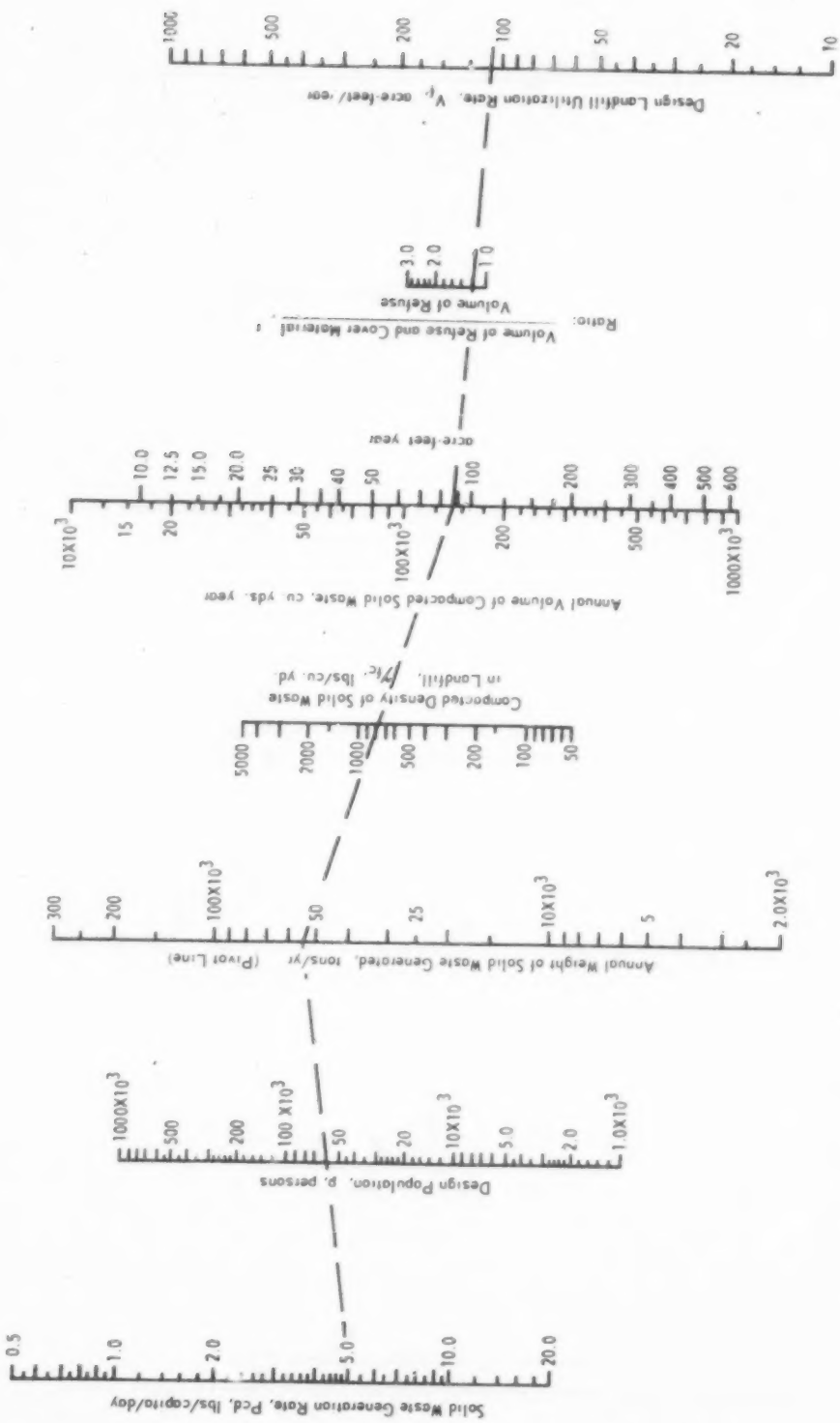

Figure F-1. Nomograph for calculating design rate of utilization of sanitary landfill volume.

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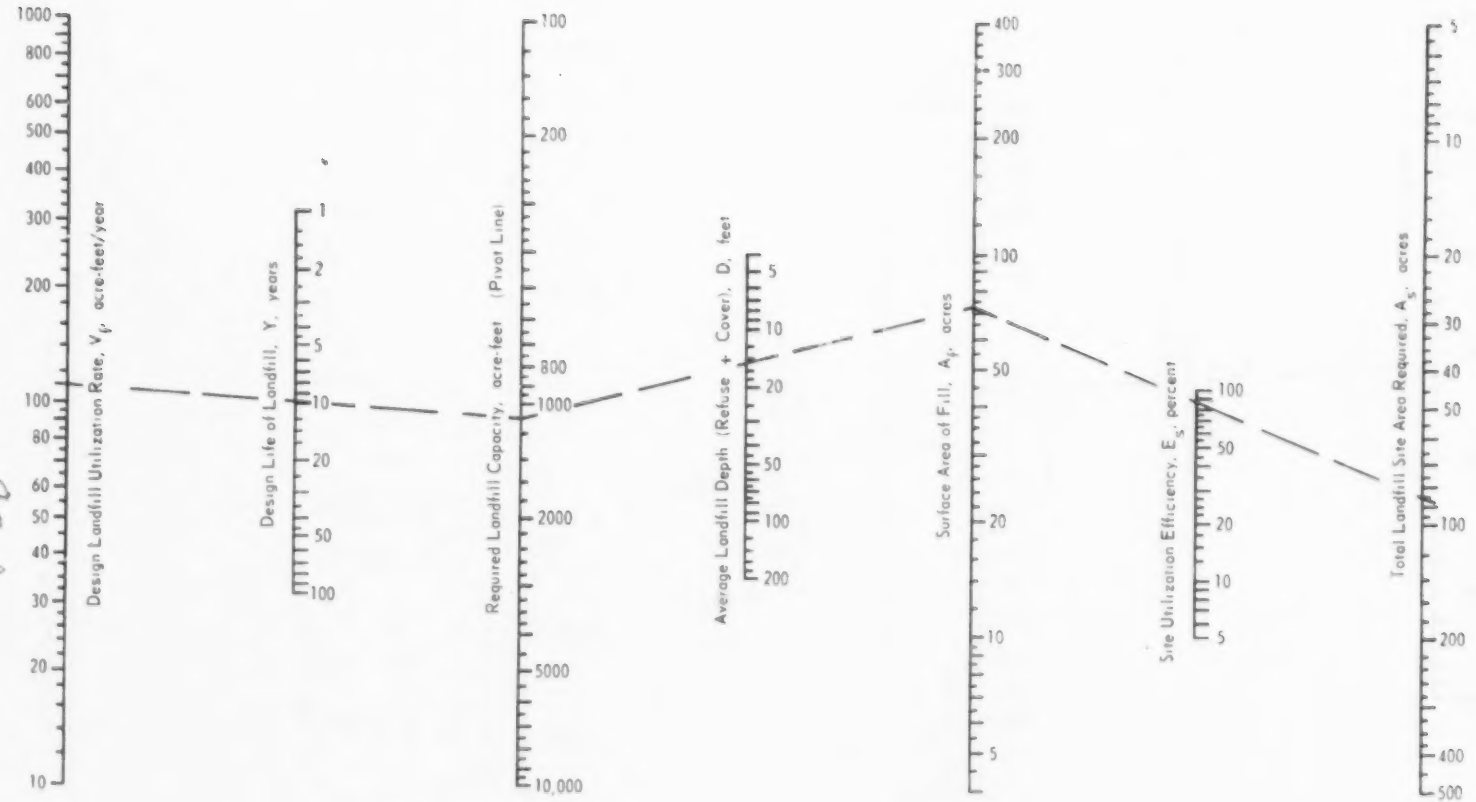

Figure F-2. Nomograph for computing surface area of solid waste fill and sanitary landfill area requirements.

APPENDIX G

EQUIPMENT REQUIREMENTS AND COSTS OF RURAL SOLID WASTE COLLECTION SYSTEM

APPENDIX G

EQUIPMENT REQUIREMENTS AND COSTS OF RURAL SOLID WASTE COLLECTION SYSTEM

Design Quantity of Solid Waste

The number of people presently without solid waste collection services in the four-county Eastern Appalachia Health Region was estimated at 61,500 by the 1968-69 State survey of community solid waste practices. These people reportedly generate solid waste at 2.0 pounds/capita/day of solid waste. In addition, recreational users of lakes in the region generate an estimated 633 tons of solid waste annually (see Appendix E), which is equivalent to the contribution of 1,811 rural dwellers. Thus, the design population for the rural bulk-container solid waste collection system in McDowell, Burke, Caldwell, and Alexander Counties is 63,300 persons.

Experience with the rural bulk collection system in Chilton County, Alabama, has indicated that bulky items as well as most yard and garden wastes are not usually emptied into the bulk containers by rural residents. The Chilton County system handles an average of only 0.68 lbs/capita/day for rural residents.[10] It therefore appeared advisable to design the rural bulk collection system for Eastern Appalachia using a maximum of solid waste generation rate of 1.00 pounds/capita/day. More containers and vehicles could be added to the system later if needed.

Container Capacity Requirements

Using the above waste generation rate and an uncompacted solid waste density of 150 pounds/cubic yard in the bulk containers, the daily solid waste volume would be:

$$\text{Solid Waste Volume} = \frac{(1.0 \text{ pounds/capita/day})\ (63{,}300 \text{ persons})}{(150 \text{ pounds/cubic yard})}$$

$$\text{Solid Waste Volume} = \underline{442 \text{ cubic yards/day}}$$

The number of 4-cubic yard bulk containers needed for twice-weekly collection and 75 percent utilization of container volume would be:

$$\text{Number of Containers} = \frac{422 \text{ cubic yards/day (3.5 days)}}{(4 \text{ cubic yards/container})((0.75)}$$

$$= \underline{490 \text{ containers}}$$

Vehicle Requirements

The number of 25 cubic yard compactor vehicles required can be computed as follows. Assuming a compacted refuse density of 440 pounds/cubic yard in the trucks, the solid waste tonnage handled daily by each collection vehicle in completing two loads would be 22,000 pounds/vehicle/day. The average quantity of solid waste to be handled daily in the four-county region is 63,300 pounds/day. Therefore, the required number of 25 cu yd compaction vehicles is:

$$\text{Number of collection vehicles} = \frac{63{,}300 \text{ pounds/day}}{22{,}000 \text{ pounds/day/truck}}$$

$$= 2.88 \text{ or } \underline{3 \text{ trucks}}$$

With the 490 containers distributed along roadsides throughout the region, each compactor truck must collect from an average of 65 containers per day to provide twice-weekly collection.

Budgetary Requirements

Capital and operating costs for the rural solid waste bulk container collection system are presented in Table G-1. The total annual cost of the bulk container system of $74,390/year is equivalent to $6.44/ton. This unit cost is higher than that listed in Table 23 (which was used for determining the optimum number of sanitary landfills) primarily because of inaccuracies in estimating the annual travel distances in-

volved in collecting and transporting the solid waste from each township. The costs presented in Table G-1 represent expenditures which the region must be prepared to meet to own and operate an adequately-sized rural bulk collection system.

TABLE G-1

EQUIPMENT AND OPERATING COSTS FOR THE BULK-CONTAINER SOLID WASTE COLLECTION SYSTEM

Item	Number or Quantity	Unit Price	Total Initial Cost	Estimated Life Years	Annual Cost $/Year
1. Collection Vehicle Operators	3	$6 000/yr	--	--	$18,000
2. Fringe Benefits for Operators	3	900/yr	--	--	2,700
3. Compaction Vehicles (25 cubic yards)	3	25,500	$79,500	6	13,250
4. Fuel, Repairs, Etc. for Compactor Vehicles	5,460 hrs/yr	2.70/hr	--	--	14,742
5. Bulk Containers (4 cubic yards)	490	250	122,500	8	15,313
6. Site Preparation for Bulk Containers	490	100	49,000	5	9,800
7. Personnel Training	3	300	900	4	225
8. Uniforms for Drivers	3	120/yr	--	--	360
9. Total			$251,900		$74,390

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